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DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, Secretary
BUREAU OF MINES
H. FOSTER BAIN, Director

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CARBON BLACK—ITS MANUFACTURE, PROPERTIES, AND USES

[redacted]

BY

R. O. NEAL and G. St. J. PERROTT

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CARBON BLACK—ITS MANUFACTURE, PROPERTIES, AND USES.

By Roy O. Neal and G. St. J. Perrott.

Part I. THE MANUFACTURE OF CARBON BLACK FROM NATURAL GAS.

By Roy O. Neal.

INTRODUCTION.

As natural gas is a waning resource in many places, increased interest has attached to the use of gas for the manufacture of carbon black. Because of a large number of requests for information on the subject, the Bureau of Mines has undertaken a detailed study of the carbon-black industry, covering the mechanical details of commercial methods, with the purpose of increasing the recovery of carbon black by such processes. A study has been undertaken of the economic factors governing the carbon-black industry, the uses and properties of carbon black, the development of more accurate methods of testing carbon black, microscopic examination of different grades of black, physicochemical study of methods of manufacture now in use, and research on new methods of manufacture.

Part I of this paper covers the engineering and economic side of the industry; the other phases of the investigation which have been under the direction of G. St. J. Perrott, of the Pittsburgh station of the United States Bureau of Mines, are discussed in Part II.

DEFINITION OF CARBON BLACK.

Confusion exists in the use of the terms lampblack and carbon black, although in American trade lampblack is generally understood to be a soot formed by the smudge process. In this process oil, coal tar, resin, or some solid or liquid carbonaceous substance is burned in an insufficient quantity of oxygen or air. On the other hand, carbon black refers to a product resulting from the incomplete combustion of gas and is deposited by actual contact of a flame upon a metallic surface.

The various carbons, such as gas-retort coke, oil-retort coke, graphite, carbon black, lampblack, vine black, wood-pulp black, willow charcoal, and blacks made from refuse material, such as leather, do not possess the same flocculent characteristics, strength of color, chemical composition, or physical structure. Each black has its specific uses, and as a rule to-day it can not be substituted for another black. To apply the usual tests to determine which black to use is often difficult because of the modification in properties when a black is combined with other substances. In this paper the black resulting from incomplete combustion of gas is discussed and throughout the paper is designated as carbon black, although in the trade it is often referred to as gas black, natural-gas black, ebony black, jet black, hydrocarbon black, satin-gloss black, and silicate of carbon. These blacks are made by one of the following methods:

1. Formation by direct contact of a flame upon a depositing surface.

2. Production by combustion of an oil, tar, etc., in an inadequate supply of air, where soot is allowed to settle slowly on the floors and walls of the collecting chambers.

3. Carbonization of solids and subsequent reduction to a state of small subdivision.

4. Production by heating carbonaceous vapors or gases to a decomposition temperature by external heating with or without air in the forming chamber. This method is usually referred to as cracking or thermal decomposition, and so far is only experimental.

There is an almost universal misapprehension that these various substances are carbon, whereas they are essentially a mixture of hydrocarbons and other organic substances that may contain considerable mineral matter.

ACKNOWLEDGMENTS.

The writer wishes to express his gratitude for the many helpful suggestions given by Mr. G. L. Cabot, who has been connected with the technical and operative details of the carbon-black industry for 38 years. Only through the valuable assistance of Mr. Cabot has it been possible to unite certain sections of this paper, particularly those dealing with the plate or "Cabot" process. To Messrs. A. E. Whiting, Fred Padgett, B. W. Rumbarger, and G. A. Williams, for useful information,. the writer is especially indebted. Acknowledgments are also due Messrs. J. H. Mann, Oscar Nelson, H. D. Briggs, N. H. Davis, P. F. Reardon W. M. McKinney, G. T. Thayer, jr., Reid L. Carr, J. D. Rowan, Geo. Taylor, W. E. Jones, E. Rutledge, J. P. Smoots, Dr. J. B. Garner, Roy Brownlee, F. Hartman, F. M. Knapp, J. A. Holden, C. A. Schwarm, and L. J. McNutt for information.

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HISTORY OF CARBON-BLACK INDUSTRY.[1]

To certain manufacturers of printing ink it was known that the carbon made by burning artificial gas in a limited quantity of air gave the ink a very glossy and intense black. The first factory in which carbon black was successfully made on a commercial scale from natural gas was erected at New Cumberland, W. Va., in the year 1872, by Messrs. Haworth and Lamb, of Massachusetts. At this plant the gas well was connected to a gas holder having a blow off from which the surplus flow of gas not required at the plant might escape. At that time no regulating appliance was known, and a large waste of gas resulted from their enterprise.

The first actual use of natural gas for light in the United States occurred in Fredonia, N. Y., in 1826, but it was not until 1872 that pipes were laid in Titusville, Pa., for domestic purposes, the gas being transported through a 2-inch main from a gas well approximately 5 miles north of Titusville. The consumption of gas at that time was not enough to foster the development of regulating devices. Large quantities of natural gas were going to waste and could be obtained at a very low price; in fact, the oil pioneers considered natural gas as a dangerous nuisance to be blown off and disposed of in any way.

In the plant at New Cumberland the gas from the gas holder passed through pipes to gas jets arranged in the same horizontal plane beneath slabs of soapstone that were pierced with a number of orifices to permit the passage of excess smoke and the waste gases. The slabs were covered by a dome or roof that was provided with a damper for controlling the ventilation. The transverse horizontal scrapers below the slabs were supported and traveled in horizontal grooves in the lower and opposite sides of the dome. These scrapers from time to time removed the deposited carbon black, which fell into sheet-iron aprons or troughs that were supported from the burner pipe. From these troughs the black fell through pipes to a container that could be changed by hand when filled. The depositing surface was kept cool by pans through which water was continuously circulated. The resulting product sold for $2.50 per pound but did not possess all the properties of the product made from artificial gas. This plant was built of wood and was destroyed by fire after running a short time; it was then moved to Saronsburg, Pa.

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[1] Taylor, G. E., The conservation of natural gas in West Virginia: Bull. of College of Eng., Univ. of West Virginia, July, 1918. Cabot, G. L., The preparation of carbon blacks from natural gas in America: Jour. Soc. Chem. Ind., 1894, vol. 13, pp. 128–130; Lampblack and carbon black: 8th Int. Cong. Appl. Chem., 1912, vol. 12, p. 13; discussion, vol. 27, p. 93; West Virginia Geol. Survey County Reports, 1912: Doddridge and Harrison Counties, pp. 656–660. Correspondence and personal interviews with carbon-black manufacturers.

The next innovation in the carbon-black industry was the use of a traveling car which hung from rails running parallel with the bench. This car carried a scraper and a shallow frame to which were attached on each side two deep receptacles of sheet iron that could be detached and emptied. The receptacles were just deep enough to pass over the burners without touching. An endless rope passing over a pulley moved the car in one direction for a given distance and then reversed it. The scrapers made contact by means of springs. Results soon showed that the dome was superfluous, that cast iron was better than soapstone as a depositing surface, and that there was practically no beneficial effect from artificial cooling.

Peter Neff built a plant at Gambier, Ohio, and through competition the price of carbon black was greatly reduced. This factory operated for 10 or 12 years, its maximum daily production being 125 pounds. Mr. Neff obtained a large number of patents, most of which were useless and impracticable.

In 1883 a considerable advance was made in the industry when L. Martin & Co. became interested in a small plant at Fosters Mills, Pa., that was not proving a financial success. Here five plates 24 feet in diameter, cast in segments, were supported by a central mast rotating with them upon bronze bedplates. Beneath these plates were fixed stationary burners of parallel, horizontal, 1¼-inch pipe. At this time carbon black could be purchased for 31 cents per pound.

In the same year A. R. Blood devised a method using a small disk or plate about 3 feet in diameter as the depositing surface. The advantage of this process over the use of 24-foot rings was that ventilation holes were not necessary and the wheels or plates could be made in one casting. A ratchet at the center revolved the plate. Beneath the plate was a scraper in the center of a radial hopper, through which the black fell into a longitudinal conveyor running beneath the row of plates. There were 16 rings in a row and 5 rows in a building. The buildings were constructed of sheet iron supported by a framework of pipe and angle iron, and had small openings near the bottom to permit the entrance of a sufficient supply of air. This method, with a few modifications, is still used and is known as the Blood or rotating-disk process.

By a patent issued in 1883, E. R. Blood began making carbon black by the roller process, using a burner with a small hole in the tip that gave a round flame. Although this method gave a very small yield of inferior color the black possessed certain properties that made it bring a high price. Even at present it is the most costly grade of carbon black on the market.

In 1892 L. J. McNutt procured a patent on the channel system of making carbon black, and a factory was constructed at Gallagher, Pa. This process used a system of channel beams turned with the flat side downward over a horizontal row of stationary burners. The channels had a reciprocating motion, being slowly drawn back and forth, and the black was scraped from the channel bottom and removed by a spiral conveyor. By using channel irons a smoother depositing surface was possible than by using unsurfaced cast-iron plates.

At this time in the industry an attempt was made to manufacture carbon black from petroleum by evaporating and burning the vapors through gas burners; the resulting product, however, contained hard particles of carbon similar to coke, which limited its utilization, and the cost of operating a plant burning petroleum vapors or gas enriched by oil vapor has proved so high as to be usually unremunerative.

A plant in West Virginia was constructed about 1902 in which the black was collected upon a hollow channel iron through which a blast of air was blown to cool the depositing surface and to increase the yield of black. This process has since been abandoned.

In 1913 G. Fernekes obtained a patent on a process for making carbon black by subjecting gas to a temperature which dissociates it into carbon and hydrogen. The decomposing chamber was heated by electric coils. This process is not used commercially.

A patent was issued to R. H. Brownlee and R. H. Uhlinger in 1916 for making carbon black and hydrogen from a hydrocarbon decomposed by burning in contact with a highly heated refractory material within an inclosed chamber, at a pressure in excess of atmospheric pressure, and then separating the black from the hydrogen. The carbon black is not collected but is blown, and its only use seems to be in making paints. The method of producing hydrogen, however, seems to be commercially practical.

Attempts have been made to increase the yield by using chlorine and carbon tetrachloride, but they have not been a commercial success. The theory back of these attempts was that the yield of carbon black would be increased by the reaction between hydrogen and chlorine in forming hydrochloric acid.

A plant has been constructed to make black from emulsified or cut crude oil, which constitutes an enormous waste in the oil fields. The waste oil was burned on hot plates and the soot was led through a chimney equipped with a Cottrell apparatus for electrical precipitation. A number of difficulties were encountered and the plant discontinued operation.

PRODUCTION OF CARBON BLACK IN UNITED STATES.

Statistics on the quantity of carbon black manufactured are very few and are difficult to correlate. Until the utilization of gas from the prolific gas fields at Monroe and Shreveport, La., 75 per cent of the world's total supply of carbon black was produced in West Virginia. Figure 1 shows the quantity and cost of gas used by carbon-black manufacturers since 1916. Data for this curve were obtained from G. E. Taylor, assistant engineer of the public service commission of West Virginia. The average price of gas has never been as high as 3 cents per thousand cubic feet, although in some districts where carbon-black factories are located the price of gas has increased to 8 cents per thousand cubic feet, thereby forcing the manufacturers to move their plants to isolated districts. In Louisiana the average price of gas is about 2 cents per thousand cubic feet; in Oklahoma the gas costs 5 to 6.5 cents per thousand cubic feet.

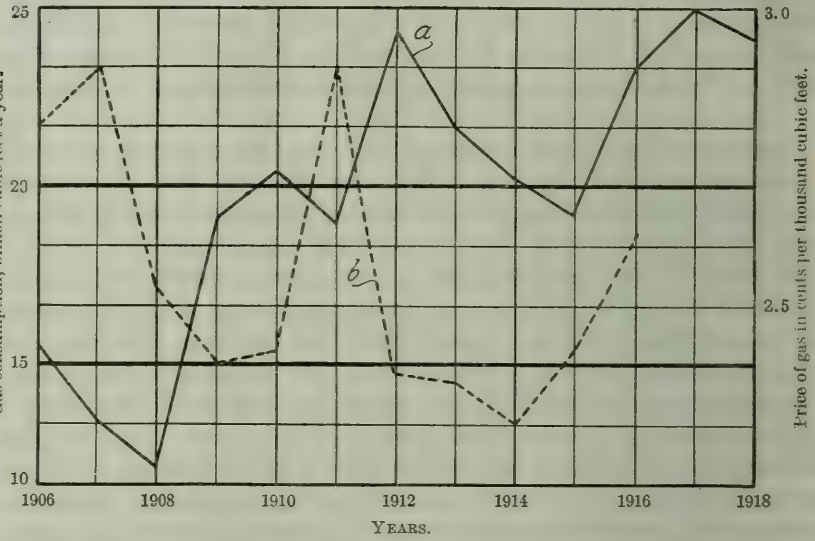

FIGURE 1.—Quantity and cost of gas used in West Virginia by manufacturers of carbon black: *a*, Gas consumption; *b*, price of gas.

TABLE 1.—*Gas used for manufacture of carbon black in West Virginia.*

YEAR ENDING JUNE 30, 1918.

	Cubic feet.
Produced by gas utilities	246,519,553,000
Produced by producers	37,552,082,000
Errors in reports	113,000
Total production as reported	284,071,748,000
Produced by carbon-black companies not included above (estimated)	5,051,765,000
Total production [a]	289,123,513,000

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[a] It is estimated that 24,830,697,000 cubic feet was used for the manufacture of carbon black.

TABLE 1.—*Gas used for manufacture of carbon black in West Virginia*—Continued.

	Cubic feet.
Consumed domestic and industrial	50,143,858,000
Consumed field and main lines	23,635,129,000
Consumed for carbon black (estimated)	24,830,697,000
Line loss, breakage of lines, etc	48,245,000
Total consumed	98,657,929,000
Transported out of State	194,952,900,000
Transported into State	4,487,316,000
Net transported out of State	190,465,584,000
Gas sold by utilities to other utilities	59,489,249,000
YEAR ENDING DEC. 31, 1917.	
Produced by gas utilities	251,935,229,000
Produced by producers	38,746,414,000
Produced by carbon-black companies not included above (estimated)	14,583,283,000
Total produced [b]	305,264,926,000
Consumed domestic and industrial	52,258,468,000
Consumed field and main lines	22,924,291,000
Consumed for carbon black (estimated)	26,062,706,000
Total consumed	101,245,465,000
Transported out of State	208,280,274,000
Transported into State	4,024,818,000
Net transported out of State	204,255,456,000

[b] It is estimated that 26,062,706,000 cubic feet were used for the manufacture of carbon black.

Recent reports of the public service commission of West Virginia, as shown in Table 1, indicate that for the year ending December 3, 1917, 8.5 per cent of the total gas produced and utilized in the State was used by the carbon-black industry, and for the year ending June 30, 1918, 8.7 per cent of the total gas produced and used was burned in the manufacture of carbon black.

Estimated production of carbon black in 1918.

State.	Pounds.
West Virginia	30,000,000
Louisiana	8,000,000
Wyoming	3,000,000
Oklahoma	1,500,000
Other States	1,000,000
Total	43,500,000

Factories are located in West Virginia, Louisiana, Wyoming, Oklahoma, Montana, and Kentucky. Several interests are contemplating constructing plants in the recently developed oil and gas field of Texas. The plants built were capable in 1918 of producing per annum the following quantities:

Capacity of carbon-black factories in six States.

State.	Pounds. [a]	Number of plants.
West Virginia	[b] 28,000,000	27
Louisiana	20,000,000	12
Wyoming	4,500,000	2
Montana	2,000,000	1
Kentucky	1,600,000	1
Oklahoma	1,500,000	1

[a] Estimated.
[b] Some of the plants have been moved to fields in other States or abandoned, so that the present capacity of plants in this State is less than the amount produced in 1918.

For an estimate of the distribution of carbon black to the trade see page 60.

The quantity of carbon black used by the rubber industry since 1917 has been abnormally high, on account of the large production of solid rubber tires for auto trucks during the war. The amount credited to export is small, on account of the closing of German and Austrian markets. Mr. G. A. Williams [2] has asserted that before the war at least one-third of the total production of carbon black was consumed by Austria and Germany. Although certain manufacturers claim that this figure is high, it is admitted that prewar exports to Germany and Austria were substantial. The increase in the quantity of black used by rubber manufacturers has more than offset the decrease in export. England, France, China, and Japan import a large amount of carbon black from American producers. For further information on the use of carbon black in rubber see page 61.

SELLING PRICE OF CARBON BLACK.

The first lot of 500 pounds of carbon black placed on the market sold for $2.50 per pound, the next 1,000 pounds brought $1.50, and the plant paid for itself in approximately three months. In 1881 the price had fallen to 35 cents per pound, in 1882 to 31 cents, and because of increased competition to 24 cents in 1883. During the next 10 years the average price was 12 cents per pound. The cost of gas steadily increased, and from 1891 to 1901 the average selling price of carbon black was 6 cents, and by 1912 had reached the low level of less than 5 cents.

An impetus was given the industry in the fall of 1915, when the beneficial result of the use of carbon black in the manufacture of rubber was discovered.

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[2] Personal interview: Fuel City Manufacturing Co., Clarksburg, W. Va.

The market price of carbon black has increased since 1912 and has not fallen below 8 cents; during 1918 it sold as high as 16 cents. When foreign markets are reopened and a stable medium of exchange and credit is established, carbon black very probably will increase in price.[3] The fluctuation in the selling price of carbon black is shown in figure 2, the price being that of the grade of black used in the rubber industry or in making ordinary printer's ink. At present one large company has four grades of black that range in price from 8 cents to 40 cents per pound. Another company manufactures only one grade, selling for about 35 cents to 40 cents per pound. The high-grade blacks possess certain valuable properties and are used for special purposes, such as making the finest lithographic and embossing inks.

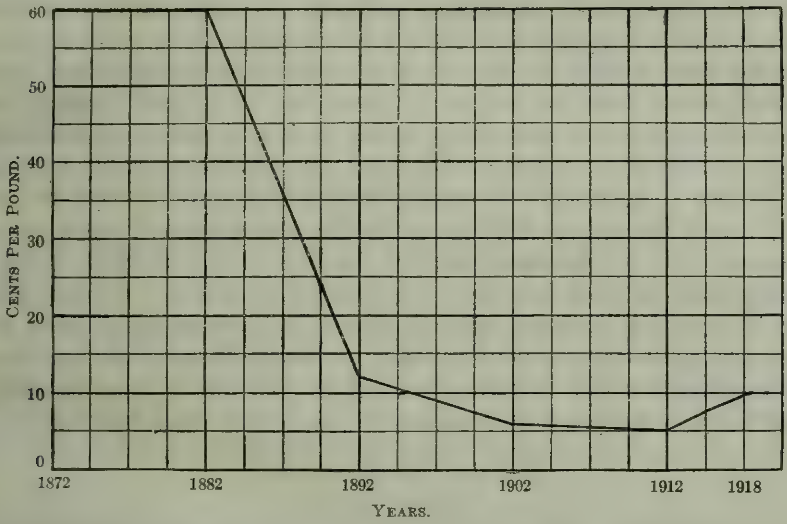

FIGURE 2.—Selling price of carbon black.

There has been a general decrease in the difference between the selling price of carbon black and the cost of manufacture. The available supply of natural gas is steadily declining, and consequently it is only a matter of time until the price increases. Evidently the most effectual way of insuring conservation of this valuable resource is raising the price.

LOCATION OF PLANT.

In contemplating the construction of a carbon-black plant, definite information should be obtained on several subjects: The distance from a railroad or a navigable stream; State laws; the depth of wells; the thickness of gas-bearing strata; gas pressure; gasoline content; and whether the gas is casing head or dry gas; amount of proved territory;

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[3] This paper was written during the early part of 1920.

history of field; drilling practice; location of field in regard to possible large gas-consuming centers; distance from trunk pipe lines for the transportation of natural gas; open-flow capacity of wells on prospective gas leases; and tests on the richness of gas to ascertain the approximate quantity of carbon black procurable per thousand cubic feet.

TRANSPORTATION FACILITIES.

Carbon-black plants are situated in isolated districts where there are no pipe lines and gas is cheap. In choosing a site for a factory, transportation facilities should be investigated thoroughly, as the necessity of building a railroad to the site chosen might make prohibitive the cost of constructing a plant. A large factory in West Virginia, for example, that is nearly 30 miles from a railroad, is greatly handicapped by the lack of adequate shipping facilities. The carbon black must be carried by boats to the railroad center; this procedure is possible only in the spring and early winter. During the summer the stream is practically dried up, and the company in order to dispose of its product during that season must haul it 16 miles over hilly roads by wagon or by motor trucks to the head of slack water. Haulage even by gasoline trucks is costly, as carbon black is light. An average railroad box car holds only 12 tons of it. By reason of the inadequate transportation facilities, the net earnings from the plant mentioned have been greatly reduced. Several carbon-black companies have had to build narrow-gage railroads in order to obtain a suitable outlet for their product.

HAZARDS IN GAS SUPPLY.

Several factors, some of them almost intangible, affect the ultimate supply of gas in a given territory. In selecting the location of a plant the life of the supply of gas from the apparent production or open flow of the wells should be estimated conservatively. An idea of the ultimate production of a well is indicated by the rock pressure, by the thickness of the gas-bearing strata, the porosity of the "sands," and the presence of intruding waters. A history of the field is necessary and also a knowledge of the drilling practice in developing the field. If proper methods are not employed, such as sealing off the gas-bearing zones in drilling oil wells, cementing off water-bearing beds,[4] and proper casing, rapid decline in the production of gas can be expected. For example, a company that was endeavoring to erect a plant with a capacity of 3,000,000 cubic feet of gas a day was not interested in any territory having an open-flow [5] capacity of even

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[4] Tough, F. B., Methods of shutting off water in oil and gas wells: Bureau of Mines, 1918.

[5] "Open flow" is an engineering term and is referred to by the courts as synonymous to "natural flow" and necessarily means the entire volume of gas that will issue from the mouth of a gas well when retarded only by atmospheric pressure.

12,000,000 cubic feet unless considerable territory remained to be drilled and the amount of gas "in sight" was to be increased materially; its experience indicated that such a quantity of gas would dwindle to an inadequate amount soon after the completion of a plant.

If a newly developed field proves extensive and prolific, a gas pipeline is usually constructed to the field. Unless the production is extraordinarily large, the price of gas will increase gradually, and as the production and rock pressure decline and compressors are applied to the gas, such value will attach to the gas that the manufacture of carbon black will become prohibitive, even though the operators may have intrenched themselves by drilling their own wells. In some localities in West Virginia, where gas formerly sold for 2.5 cents per thousand cubic feet, the price increased suddenly to 8 cents upon the introduction of compression plants and transportation lines. The manufacturers of carbon black are unable to compete with gas-distribution companies when gas sells at this figure; although the carbon-black manufacturers own the wells, it is more profitable to sell gas to pipe-line concerns than to make carbon black. The industry is necessarily migratory, although some plants have operated in one vicinity as long as 20 years. The Monroe gas field of Louisiana has become a center of carbon-black plants because it gives promise of being a field of considerable importance. The producing wells are scattered over a territory 20 miles long and 3 to 8 miles wide. Very few dry holes have been drilled, and the productive wells have an open flow varying from 5 to 25 million cubic feet a day.

GASOLINE CONTENT.

Often the gasoline content of gas may be so large that the operator can pay a high price for the gas and still find the manufacture of carbon black profitable. At several of the plants in Louisiana, West Virginia, and Wyoming the gas is treated by the absorption process [6] to recover the gasoline. The plant operators claim that stripping the gas of the gasoline vapors has little effect upon either the quality or quantity of the carbon black produced. In 1883 G. L. Cabot made some laboratory experiments concerning the effect on the yield of enriching gas by gasoline vapors. He found that by passing preheated gas over gasoline the carbon-black recovery was increased by 11 per cent of the weight of the gasoline used. The quantity of carbon black should not be changed much, as the recovery of one-tenth of a gallon of gasoline reduces the volume of the gas three-tenths of 1 per cent. The gasoline content is usually determined by an absorption method.[7]

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[6] Dykema, W. P., Recent developments in the absorption process for recovering gasoline: Bull. 176, Bureau of Mines, 1919. Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas by absorption methods: Bull. 120, Bureau of Mines, 1917.

For further information on this point the reader is referred to Technical Paper 253 of the Bureau of Mines.

TESTING NATURAL GAS FOR CARBON BLACK.

Making tests of gas for carbon black preliminary to erecting plants is a matter of great importance. Variation in the amount of carbon black obtained from different qualities of gas by the same process is shown in Table 2.

TABLE 2.—*Carbon content and quantity of carbon black recovered.*

	A. Louisiana.	B. West Virginia.	C. West Virginia.	D. Wyoming.
Methane[a] ....per cent..	94.12	70.75	65.23	46.45
Ethane ....do....	3.44	24.14	30.07	43.10
Carbon dioxide ....do....	.50	.28	1.56	.96
Nitrogen ....do....	1.94	4.83	3.14	9.49
Heating value[b]	962	1,086	1,134	1,176
Carbon per 1,000 cubic feet of gas[c] ....pounds..	33.8	39.9	42.3	44.3
Carbon black per 1,000 cubic feet of gas reported obtained..do....	.80	1.00	1.10	1.40
Per cent recovery	2.4	2.5	2.6	3.1

[a] Analyses were made by D. B. Dow, junior chemist of Bartlesville station, United States Bureau of Mines.
[b] Net heating value in B. t. u. per cubic feet at 0°C, and 760 mm. pressure.
[c] Calculated from carbon content of methane and ethane.

The quantity recovered closely parallels the percentage of ethane[8] heating value, and the amount of elementary carbon from the hydrocarbons determined by analysis. The gas from Louisiana has the lowest percentage of nitrogen, and has the highest percentage of hydrocarbons, 97.56, yet when burned at a factory it gives the smallest yield of carbon black. This result is due to the larger proportion of methane which contains 33.5 pounds of carbon per thousand cubic feet, whereas an equal volume of ethane contains 67 pounds of carbon. The two gases from West Virginia have similar compositions and give approximately the same yield of carbon black. The gas supplied to the plant in Wyoming has the highest calorific value, carbon content, and ethane content of the gases, and produces the greatest yield. From the gases richer in higher hydrocarbons not only the actual quantity of carbon obtained is larger, but the percentage of recovery increases. A chemical analysis of a gas is probably as trustworthy an indication of the available carbon black as the result obtained with a small portable apparatus in which a measured quantity of gas is burned and the deposited carbon black collected and weighed.

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[7] Dykema, W. P., and Neal, R. O., Application of the absorption process to recover gasoline from the residual gases of compression plants: Tech. Paper 232, Bureau of Mines, 1920. 41pp.

[8] For the chemical analysis of natural gas, *see* The sampling and examination of mine gases and natural gas,'' by G. A. Burrell and F. M. Seibert, Bull. 42, Bureau of Mines, 1913; and Gas analysis, by L. M. Dennis, 1913.

The writer has designed an apparatus for determining the quantity of carbon black to be obtained from an unknown gas. This apparatus is made of 16-gage sheet iron and held together with one-eighth-inch rivets. The carbon black is deposited on a plate measuring 8 by 10¾ by ¼ inches and removed by a hand-operated scraper measuring 1 by 8 by $\frac{1}{16}$ inches. Draft control is by eight 1-inch ventilating holes provided with covers pivoted above the holes, and by a revolving damper at the top of the hood. The pipe carrying the lava tips can be lowered or raised beneath the depositing plate and held at any distance by attaching a plug in the stopper holes below the supports. In the hopper is a sliding door for removing the carbon black. Lava tips capable of burning about eight cubic feet of gas per hour are used. The hood, hopper and legs are detachable and fit into the central part of the device to facilitate transporting in the field. The apparatus ready for transporting is shown in Plate I, *A;* its details in figure 3. It can be used by connecting directly to the supply of gas and by using suitable wind breaks if assembled in the field, or it can be used in the laboratory by obtaining a sample of gas under pressure in a steel cylinder.

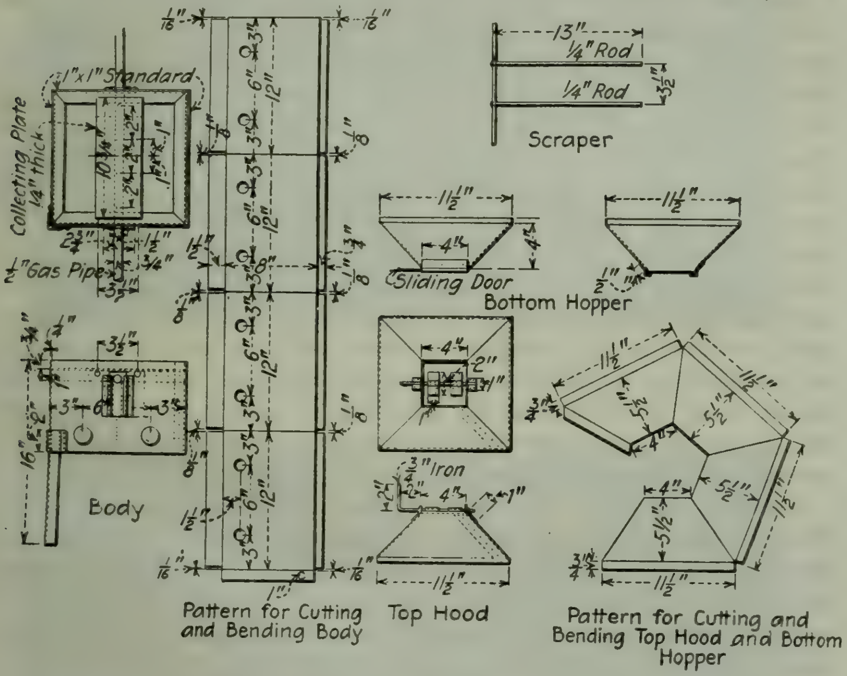

1"x1" Standard
Collecting Plate 1/4" thick
1/2" Gas Pipe
Body
Pattern for Cutting and Bending Body
13"
1/4" Rod
1/4" Rod
Scraper
11 1/2"
4"
Sliding Door
Bottom Hopper
3/4" Iron
Top Hood
5 1/2"
Pattern for Cutting and Bending Top Hood and Bottom Hopper

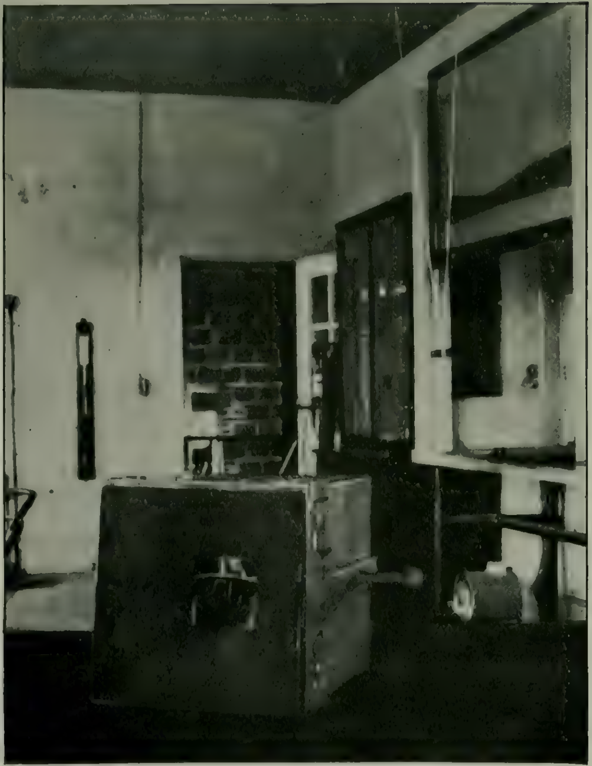
FIGURE 3.—Details of portable testing apparatus.

The source of supply of the gas to be examined is connected with a meter registering a quantity at least as small as one-tenth of a cubic foot; on this line should be a quarter-inch needle valve for limiting the flow of gas through the apparatus. Between the meter and the gas-burning apparatus is attached a U-tube for determining the pressure of the gas. The top of the lava tips should be about 2½ inches below the depositing plate, and a gas pressure of one-half to one inch of water should be maintained. These factors of course will differ for the examination of different gases, and in the preliminary tests adjustments should be made until the largest recovery is obtained. A test should last for an hour at least, during which time 15 to 20 cubic feet of gas should be burned. It is possible to make a test in the field without using the meter by previously calibrating the apparatus against a meter, different pressures on the manometer tube being observed and the time recorded. This will give fairly accurate results on volumes, provided of course the lava tips are not broken, plugged, or partly restricted by foreign matter after the apparatus has been standardized. During the test the carbon black should be removed from the collecting plate by the scraper every ten minutes, and at the end of the test the carbon deposited on the sides of the apparatus and plate is removed with a small brush. This accumulated carbon black is weighed. From the data on the volume of gas burned, the quantity of carbon black collected, and the pressure on gas, can be calculated the quantity of carbon black probably obtainable in plant operation from a given gas. This apparatus, assembled, is shown in Plate I, *B*.

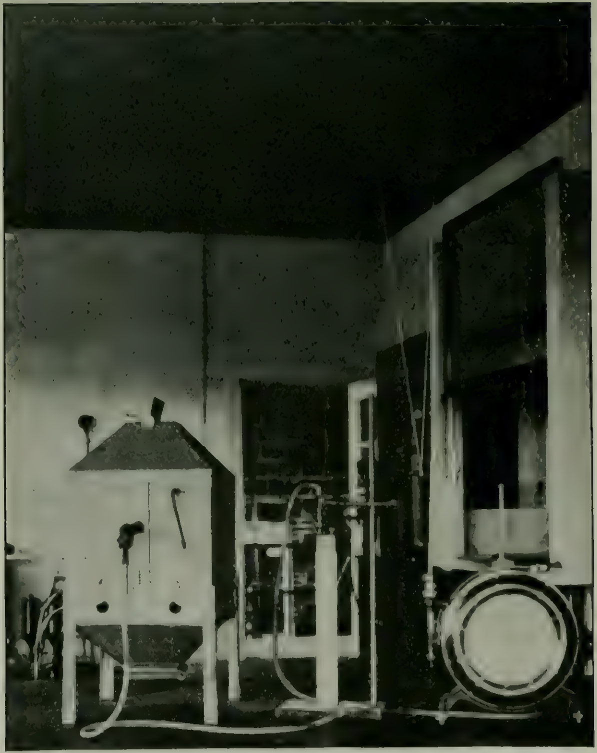
By the use of either method only comparative results are obtained. The portable apparatus gives results approximating those procured in commercial plants using the channel system, but if some other process is to be used, the apparatus should be standardized against a plant where conditions are similar to those under which the gas under test will be burned.

COMMERCIAL METHODS OF MAKING CARBON BLACK.

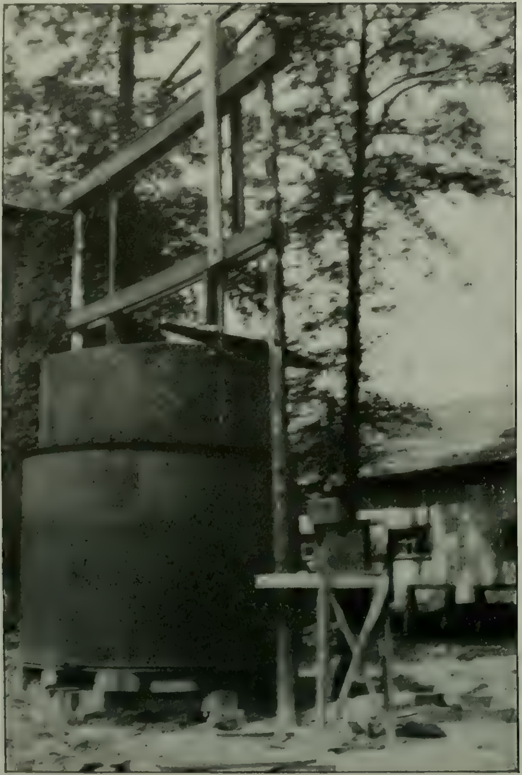
In commercial practice are four different processes of manufacturing carbon black from natural gas—the channel system, the small rotating disk, the roller or rotating cylinder, and the large-plate processes. These methods differ mainly in the size and shape of the surface upon which the carbon is collected and the rate of travel of the moving devices. The channel process is probably the best method and is the one most extensively used. Classified according to the quantity of carbon black produced, the order is as follows: (1) Channel process, (2) small rotating disk process, (3) large plate process, and (4) roller process. At present the production of carbon black by cracking or thermal decomposition methods is not extensive.



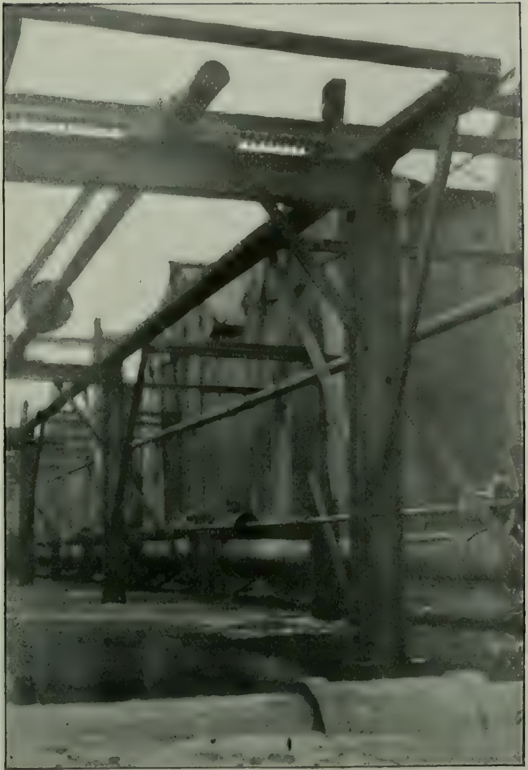
A. APPARATUS FOR DETERMINING THE CARBON-BLACK VALUE OF NATURAL GAS, KNOCKED DOWN FOR TRANSPORTATION.



B. APPARATUS FOR DETERMINING THE CARBON-BLACK VALUE OF NATURAL GAS, SET UP FOR USE.



A. MANOMETER TANK FOR REGULATING FLOW OF GAS.



B. MAIN SHAFT AND SUPPORTS OF GAS LINE AROUND CONDENSING BUILDINGS.

CHANNEL PROCESS.

THE CONDENSING BUILDINGS.

The buildings in which the channels and burners are installed are made of 24-gage sheet iron, held by wire to a steel frame made of ¼ by 1¼ by 1¼ inch angle iron. Figure 4 shows the structural details of a typical building, sometimes referred to as the condensing building. The ridge piece does not extend the entire length of the building, as spaces are left to allow the escape of the gases of combustion. The ridge pieces are flexibly attached so that the spaces can be changed and the draft regulated. In the design of some plants chimneys are provided. Along the bottom of the buildings are slits or slide doors for controlling the supply of air, but usually they are not adjusted to meet the various conditions of the weather.

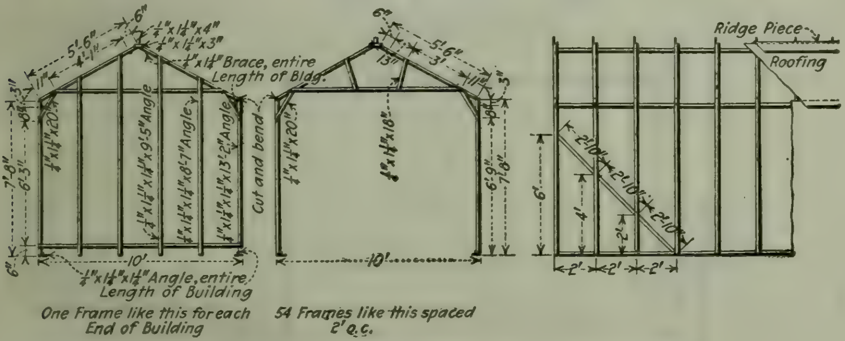


FIGURE 4.—Details of condensing building used in channel process.

A door at each end and one or two doors on each side furnish access to the interior. Buildings that have one group of channels bolted together into one table are 8 or 10 feet in width by 80 to 115 feet in length. The dimensions of two-table buildings vary from 18 to 20 feet in width and from 80 to 115 feet in length.

The buildings are arranged in parallel rows 3 to 5 feet apart at right angles to and on both sides of an alleyway about 15 feet wide. The number of one-table buildings per unit—that is, whose power is furnished by one engine—varies from 24 to 30. In some districts, particularly Louisiana, a larger yield has been obtained with one-table buildings than with larger units because of the atmospheric temperature. With two-table buildings, the number of buildings per unit varies from 12 to 16. The units have a daily capacity ranging from 60 barrels, or 3,000 pounds, to 100 barrels, or 5,000 pounds, of carbon black. The largest plant inspected by the writer had six units and consequently six packing houses, six engines for furnishing power, and an equal number of main driving shafts. The entire plant comprised 180 condensing houses.

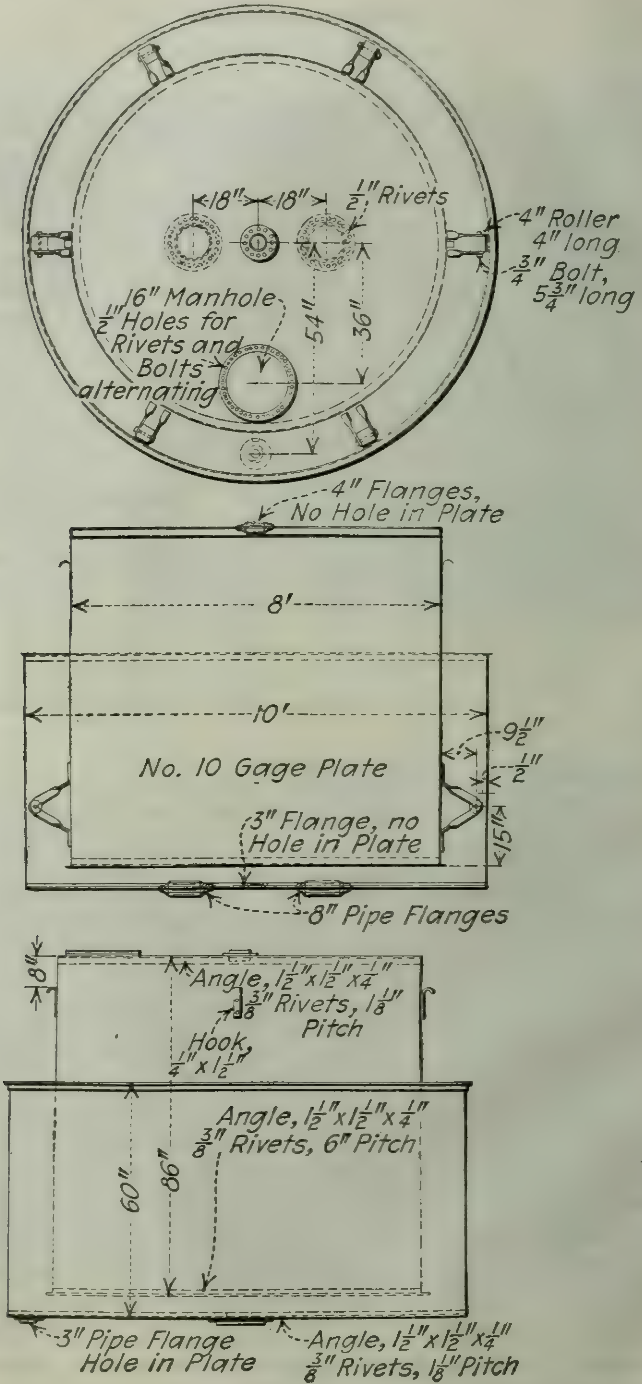


Figure 5.—Details of gasometer.

TRANSMISSION OF GAS.

The gas coming from the wells, from gasoline plants, or from mains has its pressure reduced by suitable regulators, and after passing through the regulators goes through a gasometer tank that is partly filled with water. Details of a typical gasometer are shown in figure 5. It consists of two tanks made of boiler plate, one inverted in the other. The gas passes into the inverted tank where it is held by a water seal. The pressure of the gas blowing from the gasometer will be determined by the weights on top of the tank and the height to which the tank rises. A lever arm connects the inverted tank to a butterfly valve on the intake gas line, so that as the pressure increases, the tank rises and the butterfly valve is closed. (See Pl. II, *A*.) The flow of gas is controlled by the gasometer so that the discharge pressure of the gas is less than 1 ounce.

In a plant with one-table condensing buildings, the gas is piped from the gasometer tank to a 24-inch distribution pipe made of riveted boiler plate, which lies in the middle of the alley. Two 4-inch lines connect the distributor to each building, each of which is provided with a 4-inch gate valve. In the buildings a 1¼-inch pipe connects to a 4-inch line every 8 feet. Between each 1¼-inch pipe a 1-inch rod or riser 3 inches high is welded, upon which the overhead channel work is supported. Figure 6 shows this arrangement.

In another design, an 8-inch gas line completely encircles the condensing buildings and is connected to two 4-inch inlet pipes at each end of the buildings. (See Pl. II, *B*.) The method of piping must be capable of distributing the gas evenly throughout the entire unit, and the fact that the gas is held under such low pressure demands considerable attention.

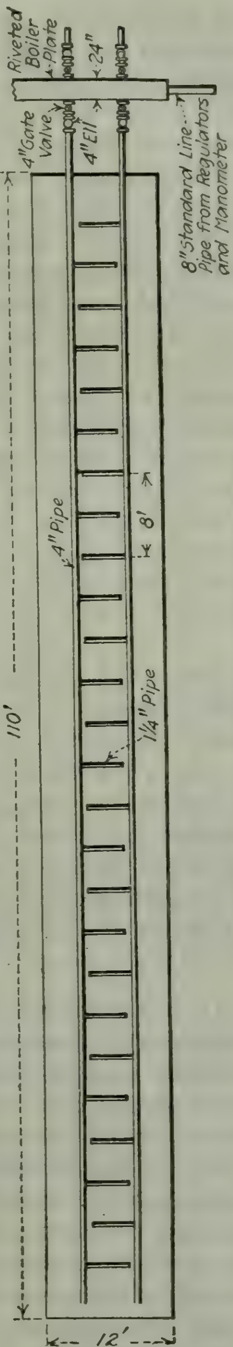


FIGURE 6.—Arrangement of gas pipes and lines of distribution.

CHANNELS.

The channels upon which the carbon black is deposited are made of mild steel, 7 to 8 inches wide and weighing about 12¼ pounds per linear foot. They hang from trucks that run on overhead rails. Standard 1¼-inch pipe resting either on concrete piers or upon the gas-distributing pipes support the channels, trucks, rails, and other accessories. The uprights are spaced approximately 4 feet, and are stabilized by means of 1 by ¼ inch cross strap-iron braces.

At the top of each upright is a small cast-iron rail chair. The steel rails weigh 16 to 20 pounds per yard. Running on the rails are 10-inch double gudgeon truck wheels. Each wheel has lugs projecting from the axis on each side to regulate its position, and it is held rigid longitudinally by two short lengths of 2 by 2 inch angle iron, although it can move within a fixed distance along the rails.

Attached to the angle iron on both sides of the truck wheel are transverse channel beams, weighing 6½ pounds per foot; to these beams are bolted the channels upon which the carbon black is deposited. Each trestle is about 6 feet wide and is called a table. Most plants have eight rows of channels on each trestle. Plate III, *A* and *B*, show an installation of this type under construction. The channels are bolted together in lengths as great as 100 feet, and the trestle work is 10 to 15 feet longer to allow for the oscillations of the table.

HOPPERS.

Below the channels are the carbon collecting hoppers, spaced approximately 4 feet apart. Each hopper is made up of three parts—the crown, the body, and the base. The crown is supported on the trestle by a ¼ by 1½ by 1½ inch angle on each side and sits loosely in the body, which is about 6 feet in width in the upper portion and tapers down to about 10 inches. The base is about 15 inches high and carries the conveyor pipe at the bottom. All three parts of the hopper are 6 inches wide, and the crown contains 4 notches which retain the scrapers, as shown in figure 8.

SCRAPERS.

There are two classes of scrapers for removing the carbon from the channels, (1) those that operate continuously, and (2) those that are in direct contact with the channels while the tables are moving in one direction only. The latter practice is considered the best, as it gives a more uniform grade of black. The scrapers are made of steel $\frac{1}{16}$ by 1¼ inches wide and 8 to 11 inches in length; they have two blades attached to a 20-inch arm carrying a loop to which is appended a weight if the scrapers remove the deposited carbon continuously. Scrapers that remove carbon only while the channels are moving in one direction are actuated by a system of levers moved by an automatic trip, termed by the workmen a "grasshopper."

Most plants have side scrapers for removing the carbon on the sides of the channel beams. A table having 8 channels would have 9 side scrapers over each hopper. The side scraper is made of a strip of strap iron ¼ by 32¼ by 1 inch, which is bent in the shape of a narrow U-tube having 15-inch legs and about a 2-inch arch. The upper ends, 3 inches from the uppermost extremity, are bent at right angles to the arch.

CONVEYORS.

Spiral or screw conveyors of galvanized iron at the base of the hoppers carry the carbon from the different condensing buildings. The conveyor under the channels is 7 or 8 inches in diameter, the outside pipe being made of sheet iron throughout and crimped at one end of each section. The screw is usually made at the carbon plants by a simple tinner's machine which cuts disks of sheet iron slightly less than 7 inches in diameter, if a 7-inch conveyor is being used, and bores a small hole in the center about 2 inches in diameter for the shaft. The shaft is made of 1-inch standard pipe supported every 8 feet by a spider bearing or conveyor hub made of cast iron. The concentric disk is cut and wrapped around the shaft in helicoidal form and is held rigid by one-eighth-inch rivets. Figure 7 shows the details of a spider bearing, truck wheels, and rail chairs. Some carbon black operators prefer to purchase spiral conveyors from machine shops where the helicoid is rolled from a single strip of metal before the pipe is inserted. This type of conveyor is strong, and resists to the full strength of the metal the lateral pressure due to pushing the material forward.

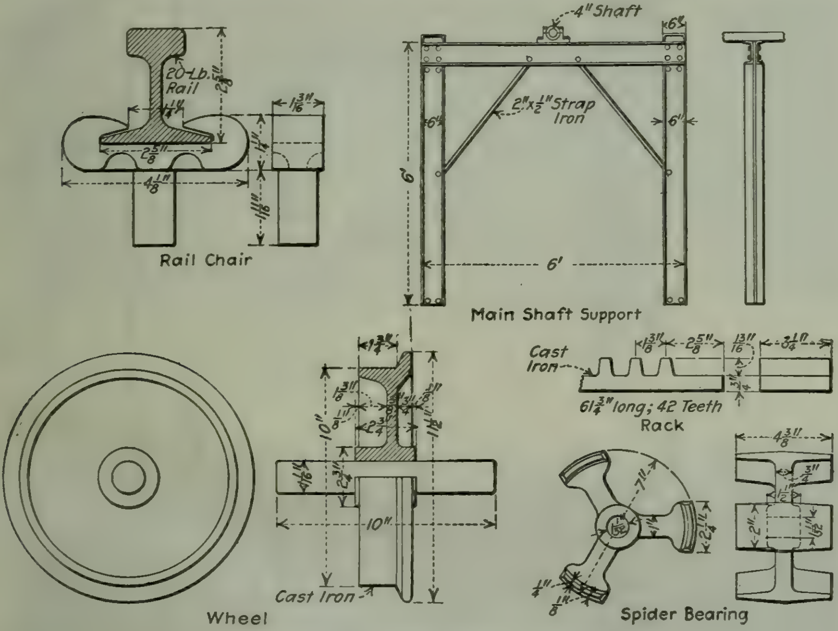


FIGURE 7.—Assembly drawing of table.

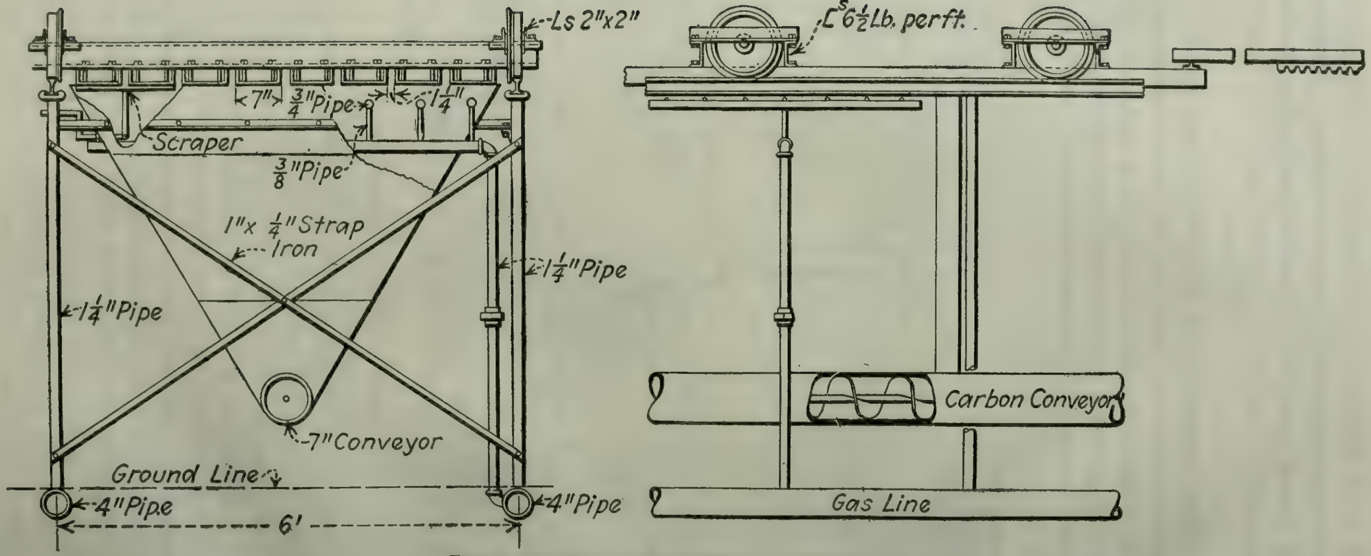
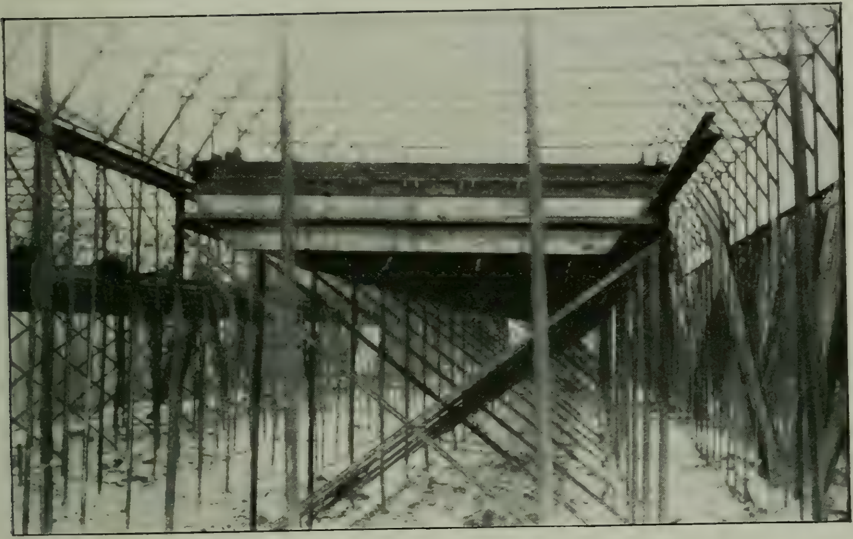
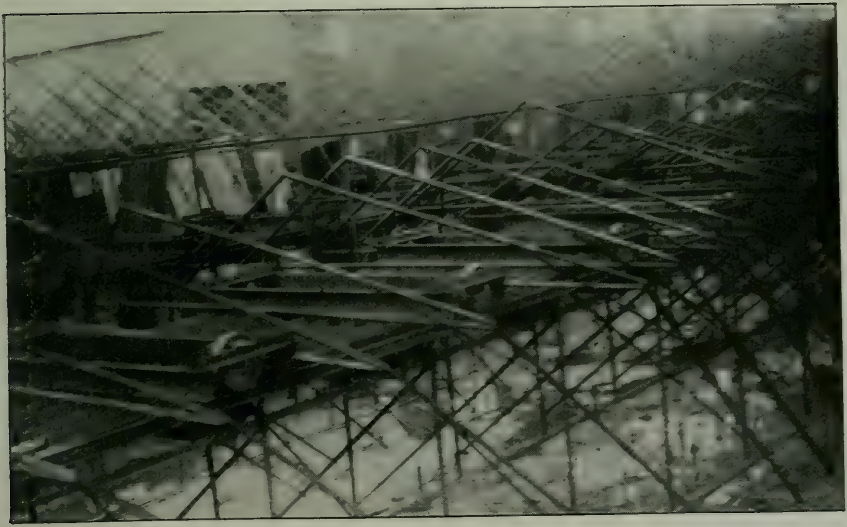


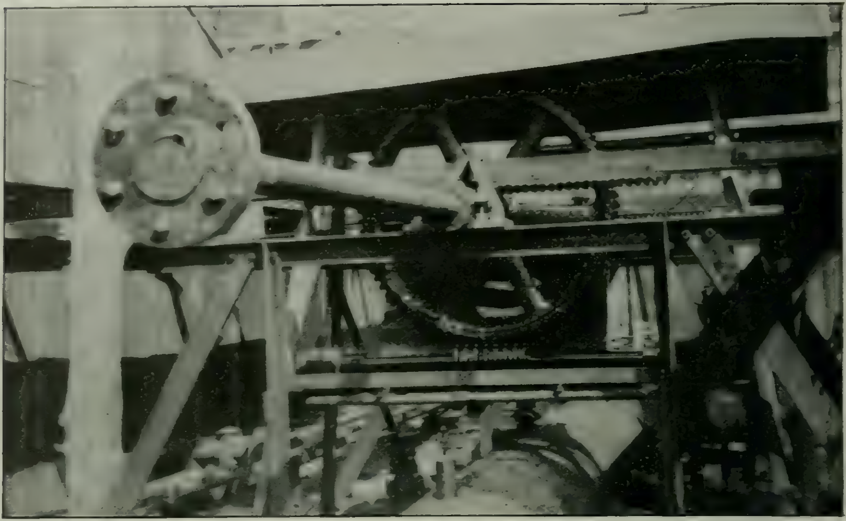
FIGURE 8.—Details of parts of machinery used in channel process.



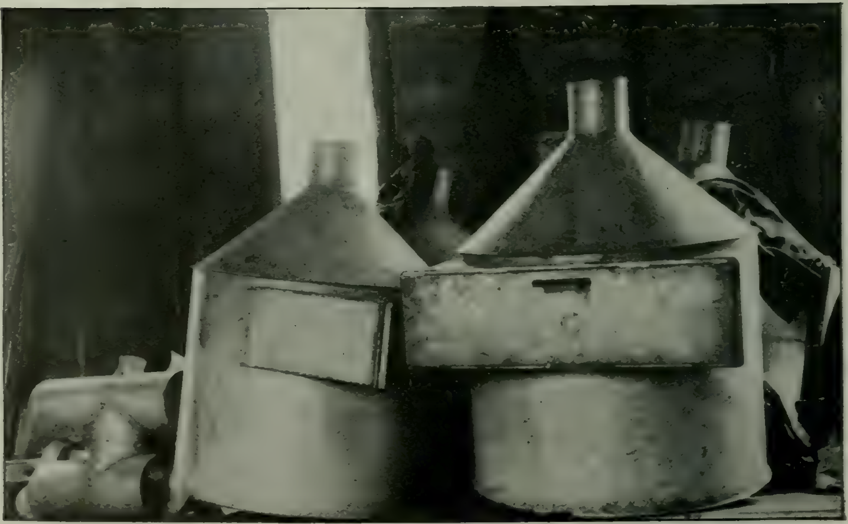
A. CHANNEL PLANT IN PROCESS OF CONSTRUCTION.



B. ANOTHER VIEW OF CHANNEL PLANT DURING CONSTRUCTION.



A. DRIVING WORM GEAR, CHANNEL PROCESS.



B. BOLTING MACHINES FOR REMOVING PARTICLES FROM CARBON BLACK.

At the discharge end of each conveyor is an overflow tee consisting of a short pipe connected to the conveyor at an angle of 30 degrees. This tee carries a sheet-iron cap. Below the tee and connected at a right angle to the conveyor is a pipe about 5 inches long and crimped at the end which delivers the collected carbon to the main conveyors on each side of the alley.

BURNERS.

The space between the hoppers constitutes one section of the trestle. In this space are the burners. The gas is delivered to the section by a 1¼-inch pipe, to which is connected a ⅜-inch pipe that carried the ¾-inch burner. The burner is parallel to and about 3 to 4 inches below the channels. Each burner holds 8 to 10 lava tips. A typical 60-barrel plant would contain the following number of lava tips: 8 lava tips per burner, 64 tips per section, 1,600 tips per building, 38,400 tips per plant having 24 buildings.

The lava tips are made of selected steatite, which is easily machined in its green condition to any desired form by turning, milling, and grinding, and is then heated to a temperature of about 2,000° F. to make it hard and strong. Most of the manufacturers of lava tips are in the vicinity of Chattanooga, Tenn.

Of the great variety of tips used the most common type burns 4 to 14 cubic feet of gas per hour. The requisites for good tips are uniform flames and uniform gas consumption. A typical lava tip has a slot 0.2 inch deep and 0.034 inch wide. The tips are tapered slightly so that by drilling in the burner pipe a hole slightly larger than the smallest outside diameter of the tip, the tips can be held securely and made gas-tight by the application of white lead. Figure 6 gives the general arrangement of burners, hopper, conveyors, and channels.

DRIVING MECHANISM AND ACCESSORIES.

Each unit is equipped with a separate gas engine, which is usually of about 20 horsepower and of the two-cycle type. Some factories make use of a simple steam engine, utilizing gas pressure instead of steam[9] thus effecting an appreciable saving in the cost of operation. The engine is connected to a shaft from which the conveyors, elevators, bolting machines, packing machines, and the reversing gear shift that actuates the channels are driven. Plate V (p. 24) gives a detailed plan of a complete carbon-black plant.

A working drawing of a reversing-gear shift is shown in figure 9. Power for the device is transmitted by a belt from the overhead drive shaft. Pulley *d* is connected to pinion *b* by means of a sleeve;

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[9] Dykema, W. P., and Neal, R. O., Application of the absorption process to recover gasoline from the residual gases of compression plants: Tech. Paper 232, Bureau of Mines, 1920.

pulley *e* in an idler and *f* actuates pinion *c* through a collar. A carriage traveling along the threaded shaft *g* shifts the belt from *f* over *e* to pulley *d* periodically by means of a lever system, consequently changing the direction of rotation of bevel gear *a*. This change takes place about every 15 minutes. The gear keyed to the shaft in the middle of the alley meshes with the worm gear *h*. Another arrangement with a worm-gear drive is given in Plate IV, *A*.

The main shaft that moves the channels extends the entire length of the alley and is usually 3 or 4 inches in diameter. It is supported by trestles 6 feet high and is made of channel steel. Details of a support appear in figure 8. There is a support with a pillow block for each pair of buildings. Couplings are placed every 16 or 20 feet.

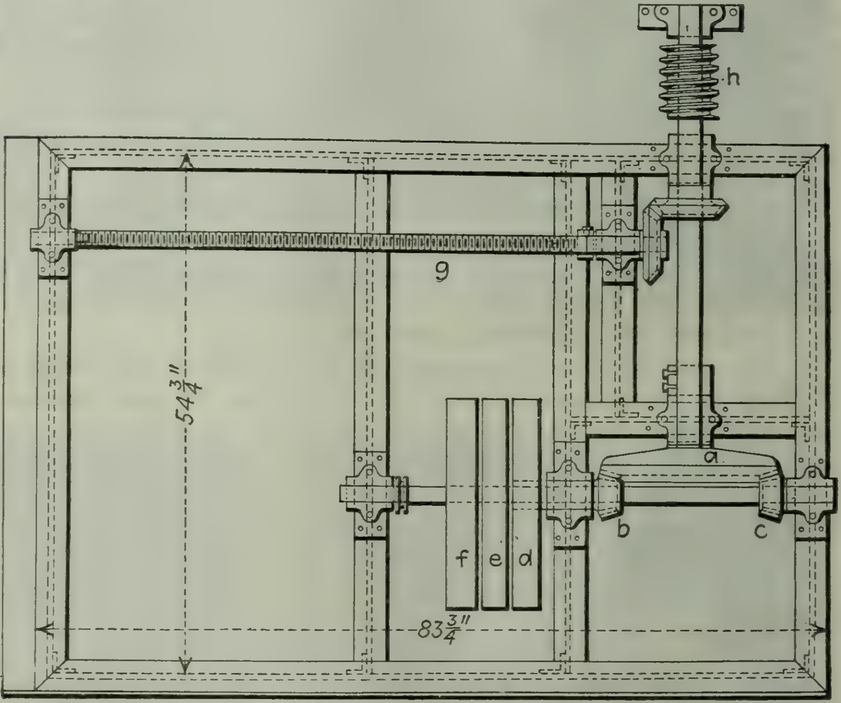


FIGURE 9.—Reversing-gear shift. *a*, Bevel gear; *b*, *c*, pinions; *d*, *e*, *f*, pulleys; *g*, threaded shaft; *h*, worm gear.

Over each support is a 13-tooth flanged pinion for engaging teeth in a rack or cog plate that is on the under side of an inverted tee steel beam connecting end trucks in opposite buildings. The rack is made of cast iron, contains 42 teeth and is about 62 inches long. Figure 7 shows the details. A stirrup of iron or roller is used to assure engagement of the rack and pinion. The entire table of channels and scrapers is moved by this rack and pinion, the channels having a straight-line reciprocating motion of 55 to 60 inches which takes 15 minutes. In a typical 60-barrel plant there is approximately 200 tons of iron and steel in the condensing buildings, not including the framework or sheet-iron covering of the buildings.

The conveyors for the carbon black are driven by a shaft belt connected to the main power shaft in the engine room. A 1-inch shaft lies on each side of the alley between the condensate buildings and transmits power to the conveyors within the buildings by means of bevel gears. The conveyor running along each side of an alley is chain driven by a sprocket wheel on the 1-inch shaft. These conveyors carry all of the black from the buildings to a chain and bucket elevator inclosed in a 16-gage galvanized sheet-iron box.

BOLTING MACHINES.

The grit, scale, and hard particles in the carbon black are removed by bolting machines, which vary greatly in design. The practice in removing particles from the black differs also. Operators at some factories pass the carbon through two bolters, some through one, and some factories are not equipped with bolting machines. At a few plants equipment includes coarse wire called a "scalper" for removing bolts, pieces of iron, and similar articles. The bolting machine may be of the horizontal or vertical type, the latter being more commonly employed.

Details of a machine often used are given in figure 10, and a view is shown in Plate IV, *B*. It is made of 20-gage galvanized iron. The steel screen used varies in size from 45 to 60 mesh, and is reinforced by a heavy wire. It is attached to a cylinder that can be removed through the drop door. A shaft having a spider with six arms, each of which carry two fiber brushes, forces the carbon black through the screen. The material not passing through the screen is discarded periodically.

STORAGE BIN AND PACKERS.

The storage bins are tapering-shaped hoppers located over the packers. They are made of galvanized iron and vary in size. Some operators use bins large enough to store two or three days' production in order to eliminate stoppage of work from trouble in the packing room, or to hold the carbon black made on Sunday, if the packers operate only six days per week. The storage bin is connected with the packers by a spout.

Packers for carbon black are similar to those used at sugar refineries. An auger inside of a tight sheet-steel tube presses the carbon black into a large paper bag. The auger is so designed as to avoid waste of the free-flowing product when the packer is stopped for changing the bags. The stock, when passing through the auger, keeps the hinged gates folded parallel to and against the top auger blades, but when the auger stops, coil springs force the gates downward against the carbon lodged between

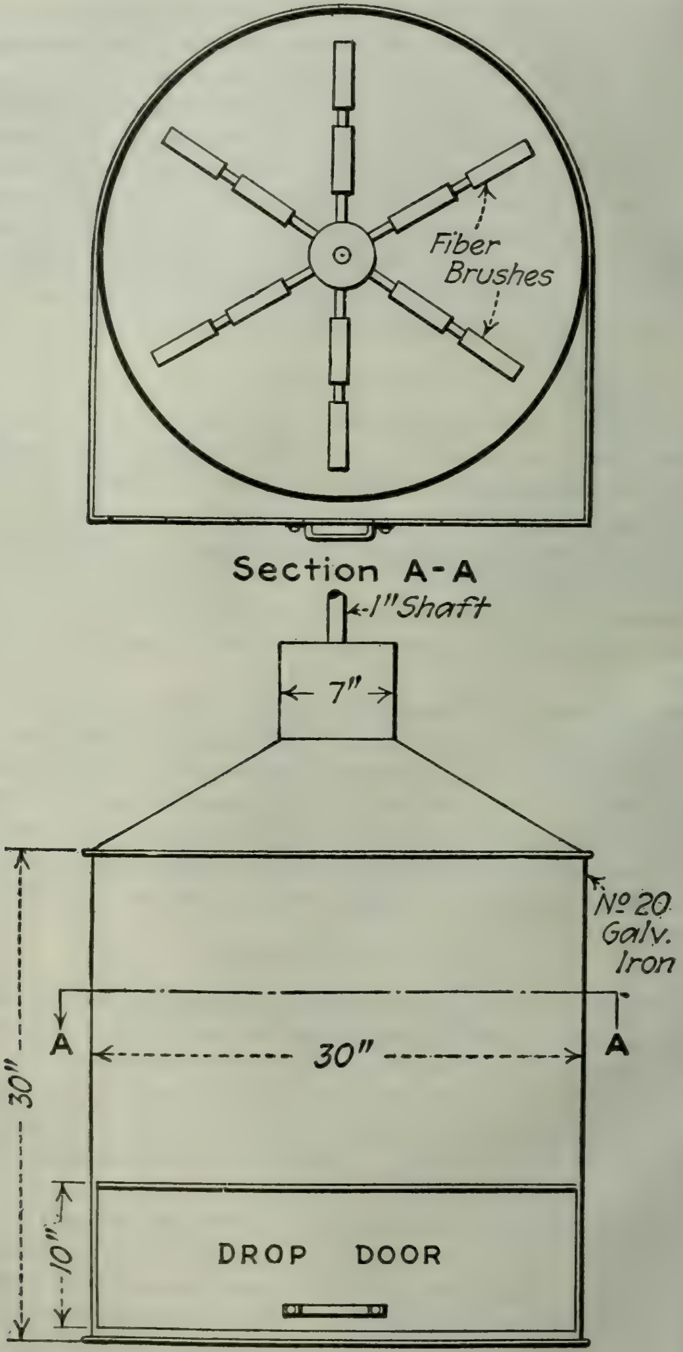
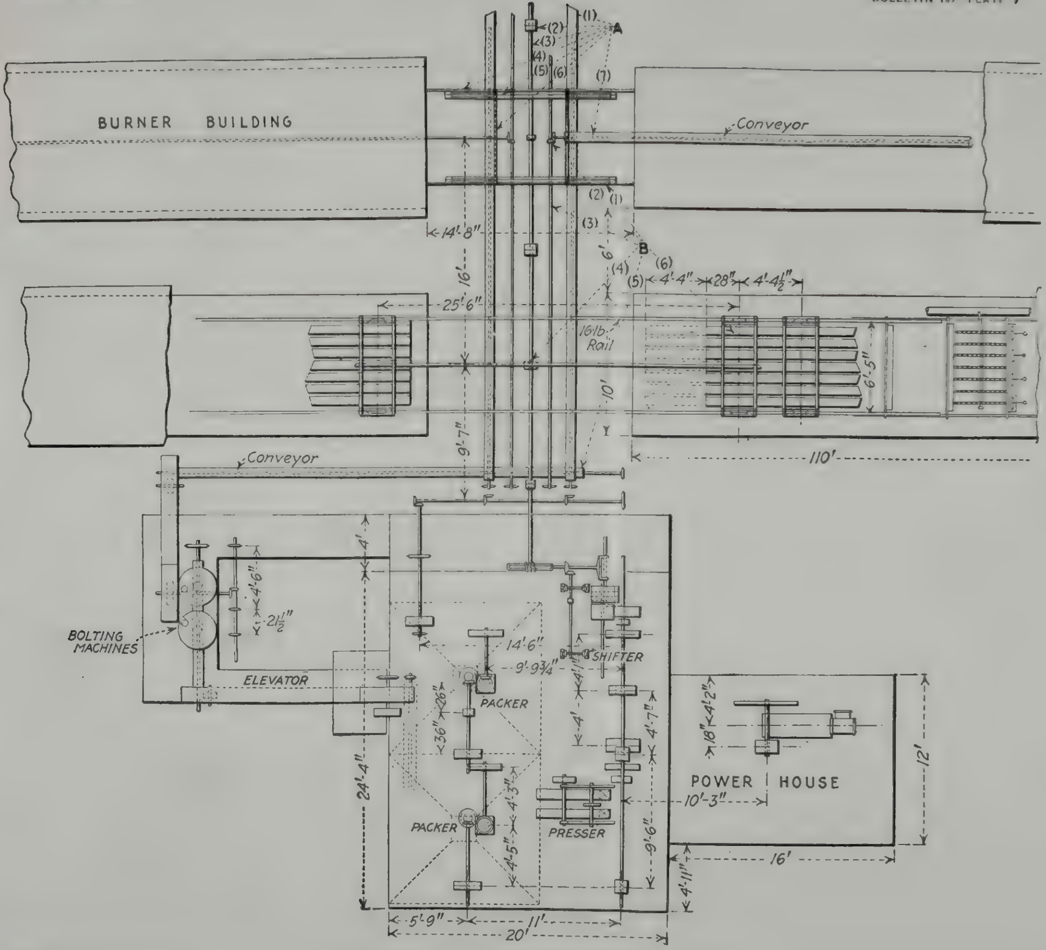


FIGURE 10.—Details of a bolting machine.



DETAILED PLAN OF A COMPLETE CARBON-BLACK PLANT.

the blades, and though they do not close the passageway completely, they confine the carbon enough to prevent leakage. The machine is gaged to pack in each bag a uniform amount, usually 12½ pounds or a quarter of a barrel. Some bags, especially those for export trade, contain 15 pounds. A simple movement of a lever causes the bevel gears to mesh and starts the packer, which stops automatically when the bag has been filled. Details of a packer are given in figure 11.

A 60-barrel plant usually is equipped with four packers that fill a bag in about 15 minutes. The inner shaft rotates slowly in order to effect the proper separation of the carbon black from the air in which it floats or which it holds mechanically. The separation of the black from the air as far as is practicable commercially constitutes the chief problem of packing. The bags are tied, and at most plants are slightly compressed in a steel-plate box, in which travels a plunger, actuated by a crank shaft or eccentric. The sides of the bag are flattened to facilitate storage and transportation. After a bag is compressed, a second paper bag is placed over the package.

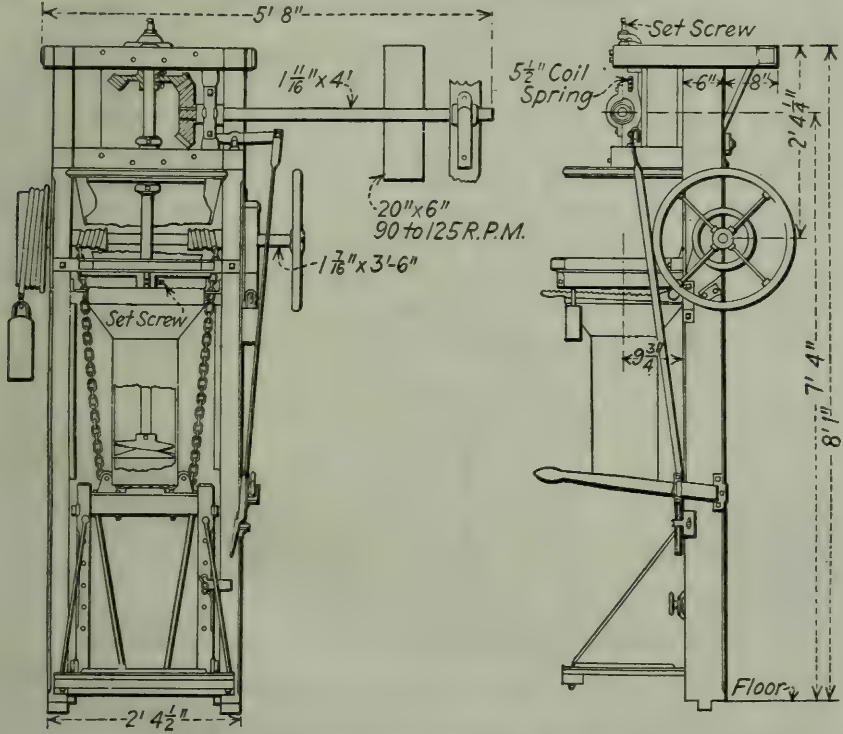


FIGURE 11.—Barnard-Moline packer of carbon black.

WAREHOUSE.

The bags of carbon black are removed by trucks from the packing building to the warehouse. If the black is intended for export it is packed in wooden boxes 3 by 3 by 2 feet each, holding from 12 to 15 bags. The warehouses are built on the main line of transportation or on a narrow-gage railroad having electric or gasoline engine-driven trucks to convey the product to a transfer point. The warehouses differ greatly in size. At one plant visited by the writer was stored a stock of 35,000 bags of black, and available spaces for as much more remained. Some warehouses are open, frame buildings, with corrugated sheet-iron roofs; some are completely inclosed sheet-iron buildings.

OPERATION OF CHANNEL PLANTS.

The channel process for packing carbon black and the construction of channel plants have been fully discussed. The operation of the channel plants may be briefly described as follows: The flames from the lava tips impinge against the under side of the traveling tables of channels, the draft being controlled by slide doors or slits at the base of the condensing buildings and by the chimneys at the ridge piece of the buildings. The gas burns with a uniform, luminous, and smoky flame. Table 3 contains analyses of gases formed in the incomplete combustion of the gas. The deposited carbon black on the under side of the channel is removed by the scrapers and falls.

TABLE 3.—*Analyses of flue gases.*[a]

	A. West Virginia.	B. West Virginia.	C. Louisiana.
	Per cent.	*Per cent.*	*Per cent.*
Carbon dioxide	1.10	3.4	2.51
Oxygen	19.60	15.0	14.30
Carbon monoxide	1.05	.1	1.36
Hydrogen	1.25	....	....
Nitrogen	77.00	81.3	81.83
Methane and ethane	....	.2	....

[a] None of the samples examined showed even a trace of formaldehyde or formic acid.

SMALL ROTATING-DISK PROCESS.

The small rotating-disk ring, or Blood process, invented by A. R. Blood in 1883, is used extensively at present. The disk upon which the carbon black is deposited is shown in Plate VI, *A*. It is made of cast iron, ranging in diameter from 36 inches to 42 inches and has a 50-inch face. The lava tips are set in a circular piece of ¾-inch standard pipe, which is about 28 inches in diameter and contains from 18 to 24 tips. The scraper for removing the carbon is continuously in contact with the disk and is set over a hopper radially with the disk. A driving gear is bolted on the disk, and a pinion meshing with the gear is attached to the drive shaft by means of a set screw. The teeth of the pinion are extraordinarily long in order to allow for the expansion and contraction of the entire length of the driving shaft. A shaft base or cap sets in the axis upon which the disk rotates, and acts as a guide and support for the driving shaft. It also stabilizes the pipe which rests on a concrete base and carries the weight of the disk. The gear and pinion actuate the disk, which makes one revolution in about 15 minutes. Figure 12 shows details of a wheel, driving gear and pinion, and shaft base. A gear and pinion, shaft base, and accessories is shown in figure 13; in this drawing the disk is not the same design, however, as that described above.

The disks are arranged in rows of 21 disks, with two or, usually, four rows per building. One unit plant has 16 to 20 buildings so that there are 84 disks per building and 1,532 disks in an 18-building factory. Each pair of rows has one conveyor and each row has a separate drive shaft extending the entire length of the building. The drive shafts are moved by a gear and pinion, power being transmitted by a 2-inch shaft in the alley. Plate VI, *B* shows how the power is transmitted to a building having four rows of disks.

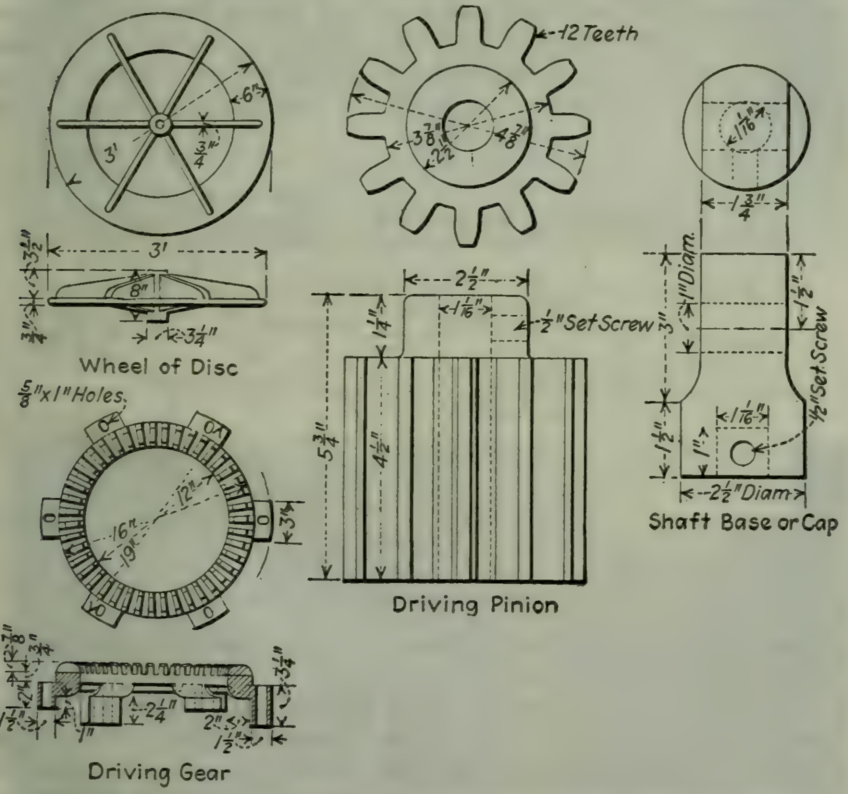


FIGURE 12.—Details of disk, driving gear and pinion, and shaft cap used in rotating-disk method.

The carbon black is delivered from the buildings as in the channel process. No gear-shifting machine is employed and the shafting is lighter than in the channel system, as the weight of the material in the condensing buildings of a typical plant using the rotating-disk method is about 150 tons.

The quality and yield of the carbon black made by the disk process is approximately the same as that made by the channel method.

THE PLATE OR CABOT PROCESS.

The plate system was invented by G. L. Cabot about 1892 and has two modifications. One method employs stationary plates 24 feet in diameter having beneath them revolving scrapers and burners; another method uses revolving plates 24 feet in diameter with stationary scrapers and burners. The first arrangement is the more widely used and is employed at a plant in West Virginia having until recently the largest output of any factory in the world. This plant had 113 plates and is shown in Plate VII, *A*. The process is also used in Louisiana. (See fig. 14.)

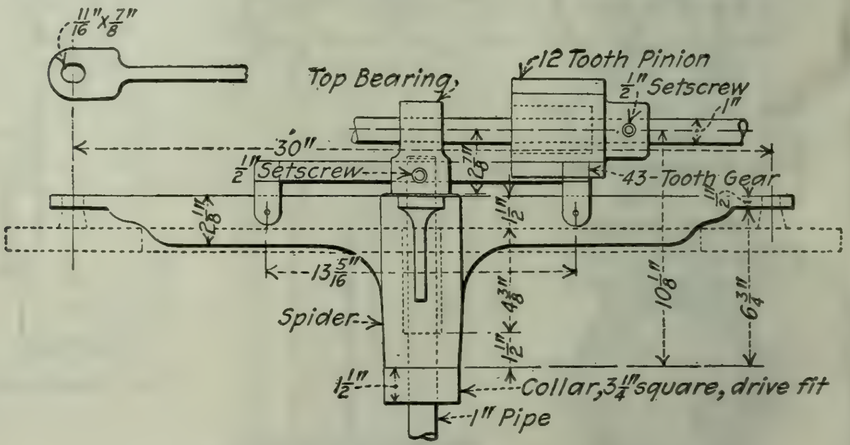
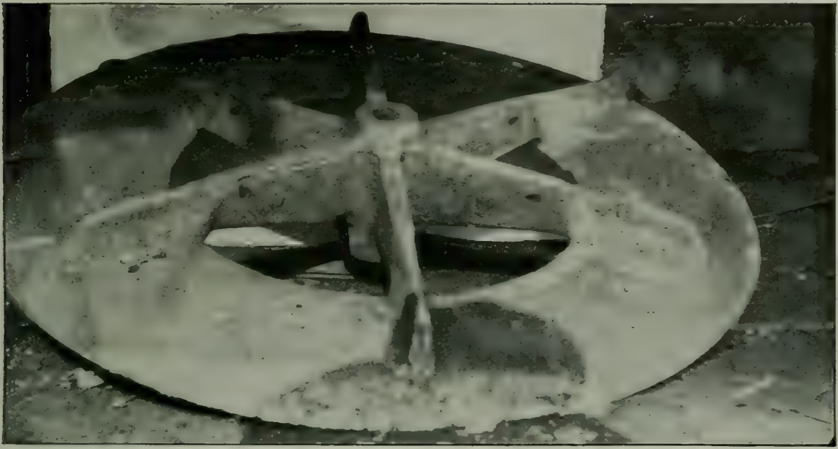
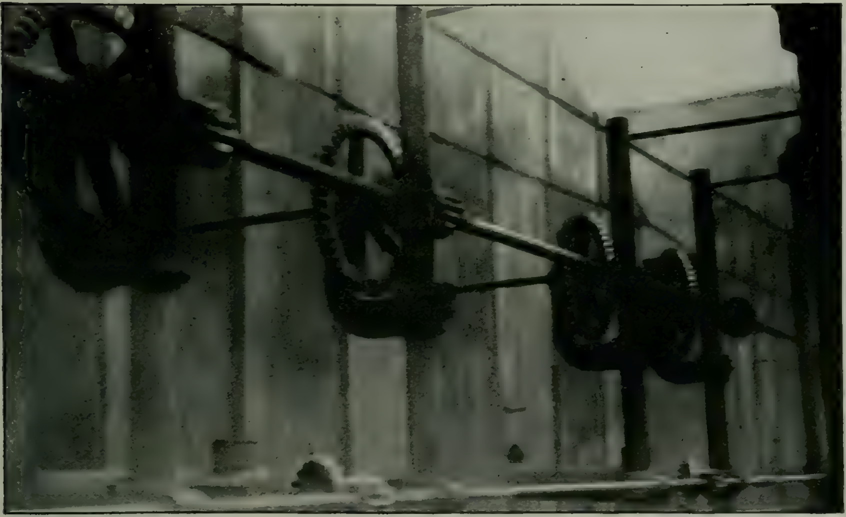


FIGURE 13.—Assembly of spider, gear, and pinion.

The iron plates are made of 48 segments, 16 in the inner row and 32 in the outer row, the over-all diameter being 24 feet. The plates are perforated with ventilator holes to allow the products of combustion to escape and to afford a means of maintaining a draft. The plate is supported by guys screwed into a cap that is shaped like a broad truncated cone. This cap rests upon the top of a hollow mast, the joint between the cap and the mast being made gas tight with asbestos. A circular building, 26 feet in diameter, made of corrugated sheet iron, surrounds the plates. Above each plate is a roof made partly of triangular pieces of sheet iron and partly of four-sided sheets of corrugated iron extending about two-thirds of the distance up the 16-foot mast, leaving therefore, in the center,

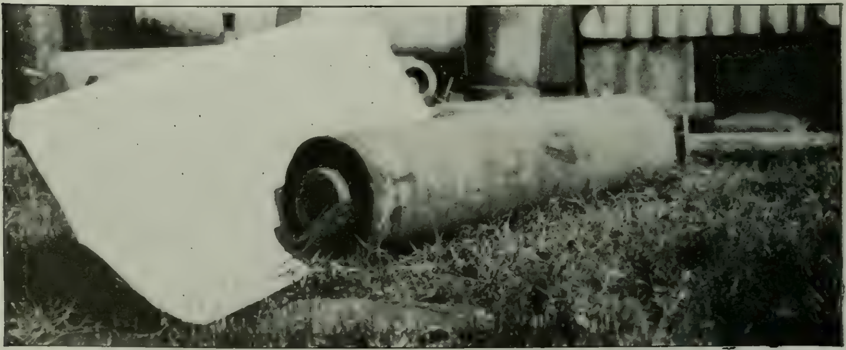


A. DEPOSITING SURFACE FOR CARBON IN ROTATING-DISK PROCESS.



B. DRIVING MECHANISM IN ROTATING-DISK PROCESS.

A. CARBON-BLACK FACTORY IN WEST VIRGINIA USING THE PLATE PROCESS.



B. CYLINDER ON WHICH CARBON BLACK IS DEPOSITED IN ROLLER SYSTEM.

an open space having about one-third the diameter of the plate, through which the products of combustion can escape.

The mast stands in a bedplate; the upper surface of the bedplate carries a groove in which steel balls run as a bearing. Upon these steel balls rests a casting having 8 arms that project outward and upward and fit into the lower ends of struts made of 2-inch pipe. On the outer end of these struts is an angle casting, into which the pipe fits, and a horizontal hole which accommodates a horizontal guy

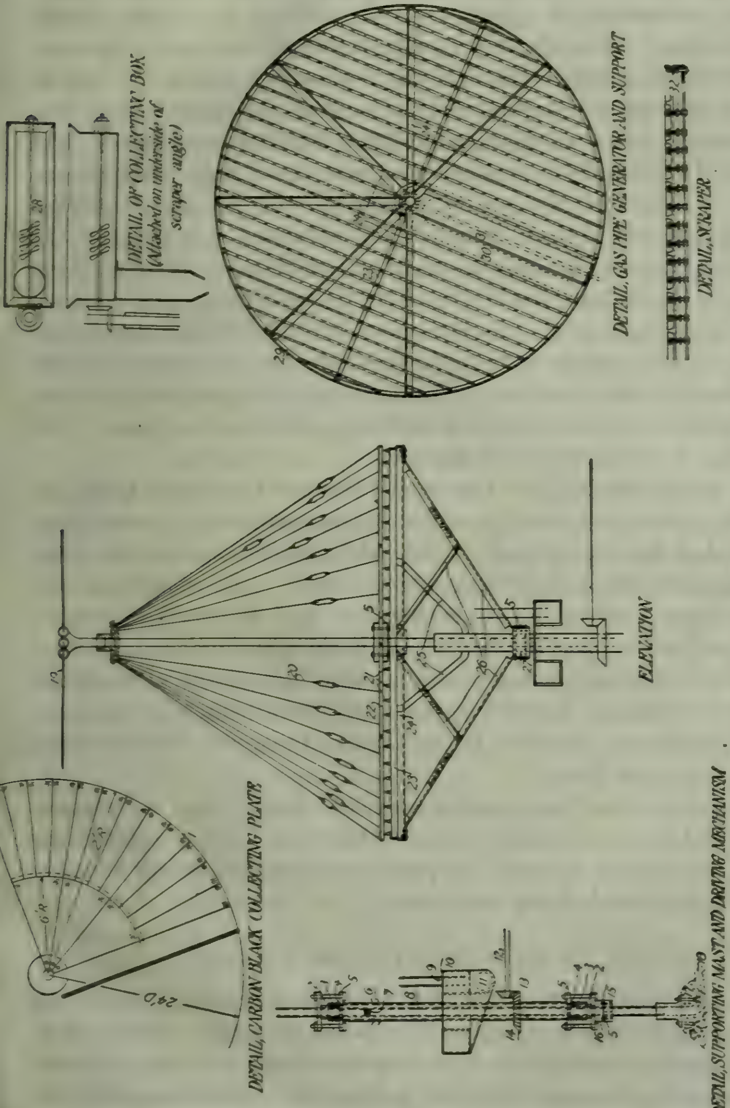

DETAIL, CARBON BLACK COLLECTING PLATE
6'-8"
2'-8"
24'-0"
DETAIL, SUPPORTING MAST AND DRIVING MECHANISM
ELEVATION
DETAIL, GAS PIPE GENERATOR AND SUPPORT
DETAIL, SCRAPER
DETAIL OF COLLECTING BOX
(Attached on underside of scraper angle)

FIGURE 14.—Details of the plate or Cabot process of making carbon black.

1. Hole for attaching guys.
2. Stuffing box and gland.
3. Packing, 4 plugged.
5. Collar and set screw.
6. Tapped for gas.
7. Inner shaft plugged.
8. Openings, gas from inner tube to outer tube.
9. Carbon black.
10. Revolving cover plate.
11. Screw conveyor.
12. Driving shaft.
13. Pinion.
14. Gear.
15. Ball bearings.
16. Loose collar.
17. Concrete base.
18. Gas intake.
19. Cable support from one unit to other unit and to ground.
20. Guy wires or rods with tightening buckles.
21. 1¼-inch gas pipes.
22. Cast-iron plates.
23. 4-inch gas pipe.
24. Angle irons.
25. Gas.
26. Angle-iron supports.
27. Stud bolts.
28. Screw or paddle conveyor.
29. Supporting and tie up angles.
30. Collecting box.
31. Angle scraper.
32. Attached rods and spring.

rod. Each horizontal guy is connected at the inner end to an octagonal plate that rotates with the burners and scrapers around the central mast. The burners fit in a gridiron of pipe lying on a circle of 4¼ by ¼-inch bar iron which is bolted to the vertical face of the angle castings. The lamp is fed by two ¾-inch holes in the central mast, which is incased in a gas box with stuffing boxes and glands above and below. This gas box revolves around the mast supported on the eight-horn casting with the burner pipe and radial black box.

The gas line from the regulators connects to the mast at the bottom; the mast is closed above by a cap from which depend the oblique guys. Slightly below the scraper box are the ¾-inch perforations that admit the gas into the gas box. To the gas box are connected two 1½-inch pipes feeding a 4-inch main in which are screwed the 1¼-inch burner pipe extending beneath the surface of the depositing plate. Each 4-inch pipe feeds over fifty 1¼-inch pipes, set at equal intervals and extending to the periphery of the circular depositing plate. The 1¼-inch pipes carry lava tips that are the same as those in the channel or disk process. The two center pipes have 60 lava tips each, and there are 1,265 tips under the entire plate. The burners make 1 revolution in 8 minutes.

Scrapers placed radially on the mast removed the black from the plates. Below the scrapers is a collecting box carrying a screw conveyor actuated by a gear and pinion, the gear sitting on the mast and the pinion on the end of the conveyor shaft. The carbon is carried to the inner end of the collecting box and descends through a vertical pipe into a circular box that discharges downward into a long conveyor running beneath the circular boxes and 2 feet from the center of the ring. Conveyors take the black from several plates to the packing house, where it is elevated to bins, and then dropped into the packing machines.

All the machinery at these plants moves so slowly that the amount of power used is surprisingly small. Only one 35-horsepower gas engine is necessary to operate 22 plates and furnish power for conveyors, packing, and bolting machinery.

ROLLER OR ROTATING-CYLINDER PROCESS.

The roller process was first used by E. R. Blood in 1883, but at the start proved unprofitable because of the small yield. Later, however, the details of operation were improved and a market for the product, which possesses valuable properties notwithstanding its inferior color, has been created. At present, this is the highest priced grade of carbon black and is utilized chiefly in making lithographic and embossing inks, and printing ink for half-tone engravings.

In the roller process the buildings or benches are 65 to 100 feet long and 25 to 35 feet wide; they are made of 24-gage straight or

V-crimped sheet iron and are wired to a small angle-iron framework. From four to ten buildings are connected to the same driving shaft or source of power.

A $1\frac{3}{4}$-inch pipe leads the gas to each set of rollers or cylinders. Some manufacturers place a small disk in the screw union in each distributing pipe before it is connected to the pipe carrying the lava tips, in order to regulate uniformly the flow of the gas under each roller. The burner pipe holding the lava tips is from 3 to 5 inches below the cylinders and usually is lower than in the channel system. The lava tips are round and have a round instead of a fishtail opening, hence the flame is cylindrical. Tips are separated $\frac{7}{8}$ inch to 4 inches, as is shown in Plate VIII, *A*.

The rollers, 3 to 8 feet in length, have a spider bearing for a $1\frac{1}{2}$-inch shaft. If made of cast iron they are about seven-sixteenths of an inch thick, $8\frac{1}{2}$ inches outside diameter, and weigh approximately 100 pounds. (See Pl. VII, *B*.) The outside of each roller is machine faced. Some operators use ordinary extra-heavy well casing in 8 or 9 foot lengths and by countersunk rivets fix spider bearings in each end for the shafting. This arrangement is cheaper and makes the plant more independent of the local foundries, although the possibility exists that the cylinders may warp and throw the driving mechanism out of alignment. At a plant using casing, however, no difficulty from warping, distortion, or scaling by heat was experienced.

The scrapers for removing the deposited carbon black are placed at the top or near the top of the rollers, and run logitudinally the entire length. They are in direct contact with the rollers and scrape continuously. In one design, V-shaped blades are attached to the opposite ends of downwardly curved metal straps, one blade being positioned for contact with one roller and the other for another. The weight of the straps and blades, borne by the cylinders, brings the blades into close contact with the rollers and makes them scrape efficiently.

Over the cylinders is a removable sheet-iron hood; it protects the cylinders from drafts, and is provided with apertures to control the ventilation within the roller chamber. Below the cylinders is a trough-shaped hopper contracted at the bottom, designed to exclude air from the cylinders, and to collect the black scraped therefrom. A screw conveyor mounted in the bottom of the hopper carries the black to the bolting machines and hence to the storage bin over the packing machines. An angle-iron frame supports the hood, hopper, and conveyors. Under each hood are nine rollers, three rollers on each shaft. Where 4-foot rollers are used there are only two rollers on each shaft, and in some designs two sets of rollers to a hopper. Each building contains two rows of hoods and hoppers, and the

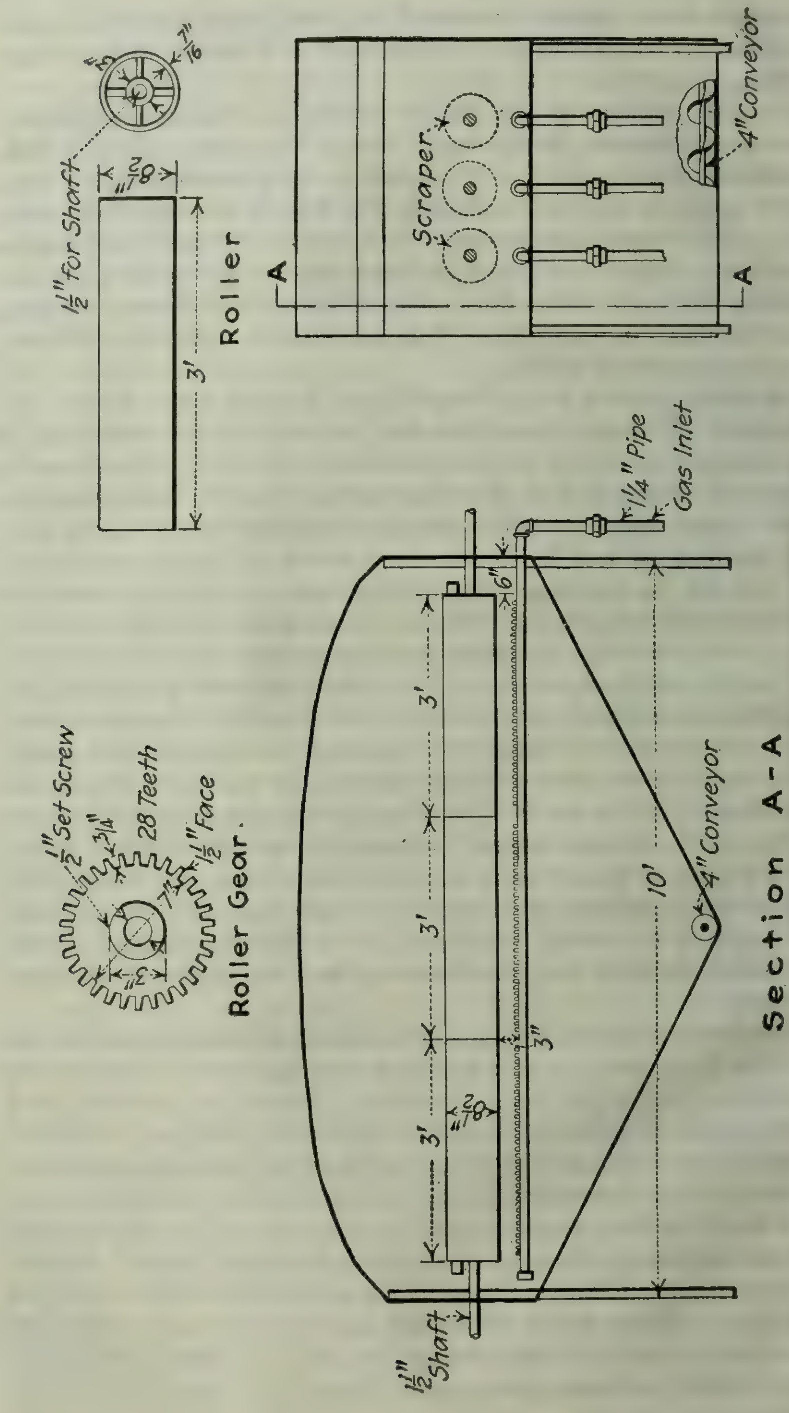
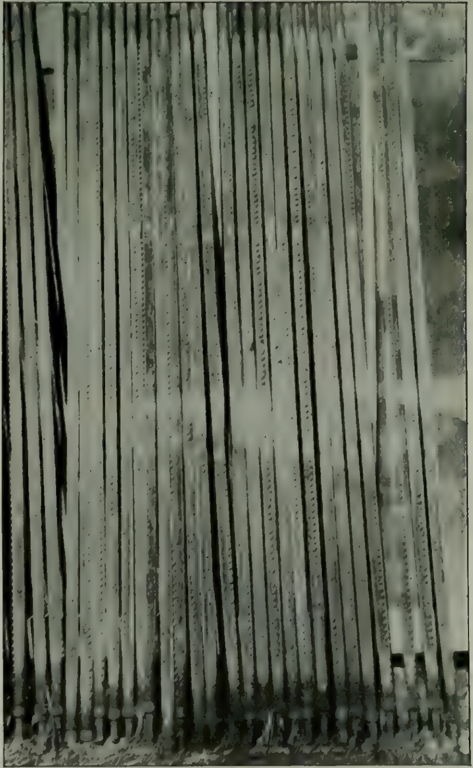
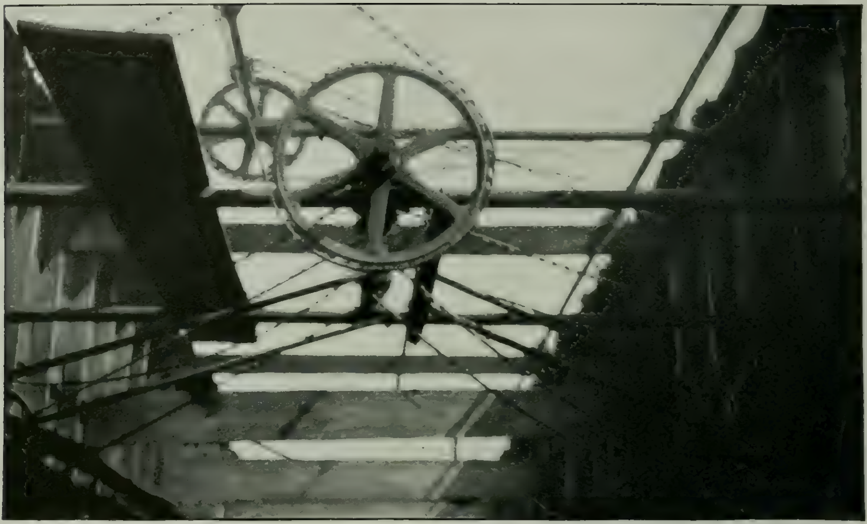


FIGURE 15.—Details of roller or rotating-disk cylinder process.



A. GAS BURNERS USED IN ROLLER PROCESS.

B. GEAR-ACTUATING CYLINDERS IN THE ROLLER PROCESS.



A. CHAIN TRANSMISSION USED IN ROLLER PROCESS.

B. A LOUISIANA CARBON-BLACK PLANT IN OPERATION.

shafting runs the entire width of the building; each shaft, therefore, actuates four or six rollers according to the length of the cylinders. Slits or slide doors in the building help to regulate the draft. A typical building has 196 to 288 rollers, 10,000 lava tips, about 24 to 32 hoods, and an equal number of hoppers.

On each shaft, which is made of hollow pipe, a worm gear with about 28 teeth and a pitch diameter of about 6 inches is attached by means of a set screw. This gear is actuated by a worm 3 or 4 inches in diameter having about 5 threads, and it makes one revolution every 15 to 45 minutes (see Pl. VIII, *B*). The grade of black determines the rate at which the cylinders revolve. The worm is mounted on a solid steel shaft that is moved by a chain and sprocket transmission from the main power line, as shown in Plate IX *A*. The conveyors, elevators, bolting machines, and packing machines are also connected to the main power shaft, which is actuated by a gas or expansion engine. Power requirements are about the same as in the channel method. Figure 15 shows details of the roller system.

GEARS USED IN CARBON-BLACK INDUSTRY.

The machinery at a carbon-black plant requires a large number of gears. Most of these are bevel gears as they are used to transmit power to the conveyors, although spur gears are used in transmitting power to bolters, scalpers, etc., and worm gears move the cylinders in the roller process, and also connect the reversing gear shift to the main drive shaft which actuates the rack and pinion in the channel system. (See fig. 16.)

Diametral pitch is the number of teeth to each inch of pitch diameter. The word diameter, when applied to gears, always means pitch diameter.

If the teeth are shaped properly, the linear velocities of the two wheels are equal, and the angular velocities or speeds of rotation are inversely proportional to the number of teeth and to the diameter. Thus a gear that has twice as many teeth as one mating with it will revolve just half as many times per minute.

In ordering standard gears and pinions it is only necessary to specify circular pitch, bore, face, and ratio of the number of teeth on the gear to the number of teeth on the pinion. Although there is no standard rule, the width of the faces of the teeth is generally made two or three times the circular pitch.

At carbon-black plants the temperature changes give rise to a special problem which is solved by using pinions whose facial dimensions are four or five times those of the gears so that should there be a sudden expansion or contraction in the shaft, the gear and pinions would still mesh. Should bevel gears be used, contraction might possibly prevent intermeshing, and expansion might break the teeth or force the shafting out of alignment, causing a waste of power and undue wear upon gears and bearings; in fact some bevel gears have worn away from this cause as much as three quarters of an inch. Frequently a device is resorted to which is not strictly mechanical, but which, nevertheless, gives good results under the conditions peculiar to this industry, namely, a bevel wheel is driven by a spur gear. The bevel is flat, perhaps five or six times the pitch diameter of the spur that drives it. Obviously the wear and tear on the cogs is uneven and greater than with a true bevel properly adjusted, but the arrangement has the great advantage that as the shaft carrying the spur gears expands and contracts, the long cogs on the spur wheels always engage the teeth of the bevel gear; as the power required is very small in proportion to the size of the gears and the motion is very slow, the extra wear and friction caused by this mathematically inaccurate method is of minor importance and far less injurious than the evils that might otherwise result from the expansion and contraction of the driving shaft. Some of the gears installed in carbon-black factories are not standard, but are "bastard" and are cast from special patterns. Tables 4 and 5 contain data of value in the construction of gears.

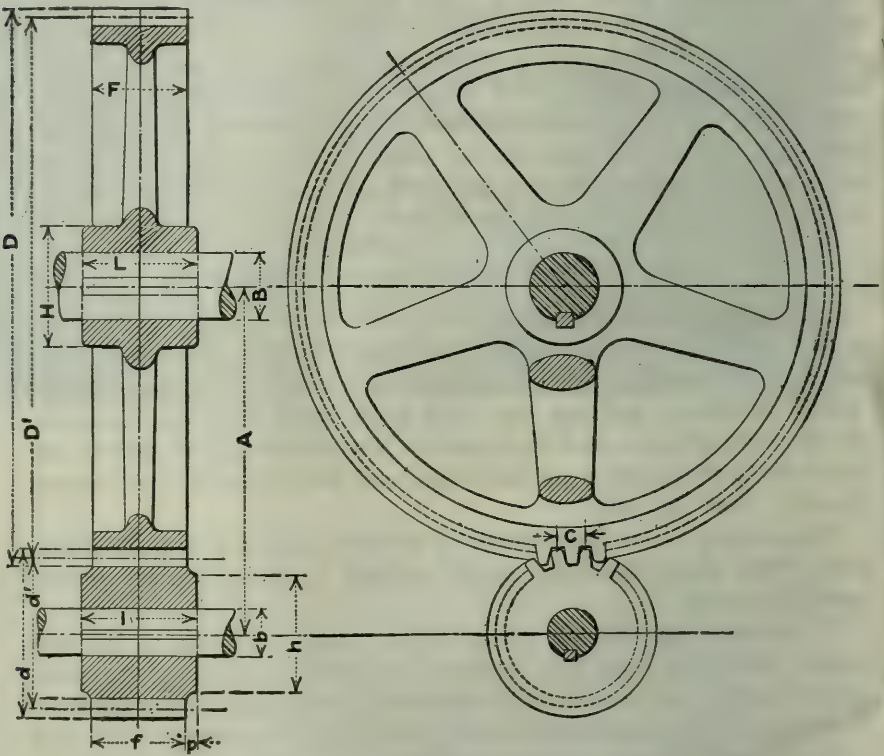


FIGURE 16.—Details of spur gear and pinion.

In the disk process especially gears are exposed to an intense heat that practically eliminates lubrication, and as a result wear and frictional losses are large. Maximum service may be obtained by the following procedure:

1. Gears and pinions should have ample strength, ductility, wearing surface, and hardness.
2. Installations should be properly made. Remember that badly worn gears will wear new pinions unduly, and that old pinions unduly wear new gears.
3. Gears should be kept in mesh on true centers in proper alignment. This necessitates proper maintenance of bearings.
4. Lubricate gears where possible.
5. Inspect gears at intervals.

If the care as specified above is not given the gears they soon fail to mesh accurately and serious evils result; power escapes in transmission; bearings wear unevenly, throwing the shifts out of line, and in turn causing gears, bearings, and other parts to wear faster; vibration produced in the gears causes increased wear and tear.

TABLE 4.—*Circular pitch of gears with its equivalent in diametral pitch, depth of space, and thickness of tooth.*

Circular pitch (inches).	Diametral pitch.	Thickness of tooth on pitch line.	Depth to be cut in gear.	Addendum.[a]
6	0.5236	3.0000	4.1196	1.9098
5	.6283	2.5000	3.4330	1.5915
4	.7854	2.0000	2.7464	1.2732
3½	.8976	1.7500	2.4031	1.1140
3	1.0472	1.5000	2.0596	.9550
2¾	1.1424	1.3750	1.8882	.8754
2½	1.2566	1.2500	1.7165	.7958
2¼	1.3963	1.1250	1.5449	.7162
2	1.5708	1.0000	1.3732	.6366
1⅞	1.6755	.9375	1.2874	.5968
1¾	1.7952	.8750	1.2016	.5570
1⅝	1.9333	.8125	1.1158	.5173
1½	2.0944	.7500	1.0299	.4775
1⅜	2.2848	.6875	.9441	.4377
1¼	2.5133	.6250	.8583	.3979
1⅛	2.7925	.5625	.7724	.3581
1	3.1416	.5000	.6866	.3183
15/16	3.3510	.4687	.6437	.2984
⅞	3.5904	.4375	.6007	.2785
13/16	3.8666	.4062	.5579	.2586
¾	4.1888	.3750	.5150	.2387
11/16	4.5696	.3437	.4720	.2189
⅝	5.0265	.3125	.4291	.1989
9/16	5.5851	.2812	.3862	.1790
½	6.2832	.2500	.3433	.1592
7/16	7.1808	.2187	.3003	.1393
⅜	8.3776	.1875	.2575	.1194
5/16	10.0531	.1562	.2146	.0995
¼	12.5664	.1250	.1716	.0796
⅛	25.1327	.0625	.0858	.0398
1/16	50.2655	.0312	.0429	.0199

[a] Distance from pitch line to top of tooth.

TABLE 5.—*Circular pitch of gears.*

[Circular pitch is the distance from the center of one tooth to the center of the next, measured on the pitch line.]

To find—	Having—	Rule.
Circular pitch	Diametral pitch	Divide 3.1416 by diametral pitch.
Do	Pitch diameter and number of teeth.	Divide pitch diameter by product of 0.3183 and number of teeth.
Do	Outside diameter and number of teeth.	Divide outside diameter by product of 0.3183 and number of teeth plus 2.
Pitch diameter	Number of teeth, circular pitch.	Multiply number of teeth by circular pitch, by 0.3183.
Do	Number of teeth and outside diameter.	Divide product of number of teeth and outside diameter by number of teeth plus 2.
Do	Outside diameter and circular pitch.	Subtract from outside diameter the product of circular pitch and 0.6366.
Do	Addendum and number of teeth.	Multiply number of teeth by addendum.
Outside diameter	Number of teeth and circular pitch.	Obtain continued product of number of teeth plus 2, circular pitch, and 0.3183.
Do	Pitch diameter and circular pitch.	Add to pitch diameter the product of the circular pitch and 0.6366.
Do	Number of teeth and addendum.	Multiply addendum by number of teeth plus 2.
Number of teeth	Pitch diameter and circular pitch.	Divide the product of pitch diameter and 3.1416 by the circular pitch.
Thickness of tooth	Circular pitch	One-half the circular pitch.
Addendum	Circular pitch	Multiply circular pitch by 0.3183.
Root	Circular pitch	Multiply circular pitch by 0.3683.
Working depth	Circular pitch	Multiply circular pitch by 0.6566.
Whole depth	Circular pitch	Multiply circular pitch by 0.6866.
Clearance	Circular pitch	Multiply circular pitch by 0.05.
Do	Thickness of tooth	1/10 thickness of tooth at pitch line.

THERMAL DECOMPOSITION.

Although several patents for cracking or thermal decomposition methods of producing carbon black from natural gas have been granted, at present only one company is operating such a process on a commercial basis. This plant decomposes the gas for the hydrogen and does not even collect the carbon formed.

The carbon black produced by this procedure contains hard particles, is grayish in color, and possesses a high apparent specific gravity. One sample the writer examined contained 5.38 per cent of matter that was soluble in chloroform and possessed only one-fifth the tinting strength of ordinary carbon black. Some of the product showed flakes of naphthalene and its utility in the rubber-tire industry was thereby much impaired. The product thus far made by thermal decomposition is almost unmerchantable, has been used successfully only in making cheap paints, and has sold for 1 to 2 cents per pound.

In one cracking process for petroleum a large pipe with walls 1½ inches thick is placed in a vertical position. The gas is introduced in the lower portion of the pipe and ejected from a side connection located near the top. A temperature of 1,500° F. is maintained by several circular rows of gas torches. The carbon deposited upon the inner walls of the pipe is released by a revolving mechanism that consists of a shaft to which are attached chains running the entire length of the furnace; the chains on revolving scrape the carbon from the inner wall of the pipe. The difficulty with this process is the rapid deterioration of the pipe and the large content of iron scales in the carbon black. Although a yield of from 8 to 10 pounds has been obtained per thousand cubic feet of gas, the product is of no commercial value.

In another process the cracking chamber is lined with fire brick, and by admitting at intervals a blast containing a mixture of air and gas, it is heated to 1,500° F. The carbon liberated is carried over by the blast of gas and is collected in separators or in bags.

COMPARISON OF DIFFERENT PROCESSES.

The channel, rotating-disk, and large-plate methods produce approximately the same yield of black per thousand cubic feet of gas. The roller system produces considerably less carbon than any of the other processes, but the resultant product is much more valuable and is utilized for special purposes. Table 6 shows the yield produced by various processes in different fields.

TABLE 6.—*Yield of carbon black in different fields.*

Plant number.	State.	Process.	Carbon black per 1,000 cubic feet gas.
			Pounds.
1	Louisiana	Channel, 2-table	0.78
2	.....do	Channel, 1-table	.95
3	.....do	.....do	.80
4	.....do	Large-plate	.80
5	West Virginia	.....do	1.10
6	.....do	Rotary-disk	.95
7	.....do	Roller	.80
8	.....do	Rotary-disk	1.00
9	.....do	Channel, 2-table	1.12
10	.....do	Channel, 1-table	1.30
11	.....do	Rotary-disk	1.40
12	Oklahoma	Channel	1.20
13	Wyoming	.....do	1.40

Plants of the channel system can be constructed almost entirely from standard forms; this feature simplifies the enlargement of the channel type of plant. The cost of construction is less than that of any other type of carbon-black factory. The large-plate method has the disadvantage of requiring special castings which are so large that a greater initial cost of construction is entailed than in other types. For a plant capable of producing a large output, however, the power requirements are less than for plants operated according to other methods. The rotating-disk process requires a special casting, but it has the advantage over the channel method that the plants are more flexible. Part of the disks in a condensing building may be out of order, yet the remaining rings will continue to operate, and it will not be necessary, as in the channel method, to eliminate an entire condensing building during repairs.

The roller system produces the smallest yield and requires the largest depositing surface per pound of black made and per thousand cubic feet of gas burned of any type of plant, as Table 7 indicates. The demand for black made by this process is small, and the present production can supply it. (See Plate IX, *A*.)

TABLE 7.—*Comparison of different methods of making carbon black.*

Plant number.	Location.	Method	Area of depositing surface per burner tip.[a]	Square feet per pound of carbon black.	Square feet per 100 cubic feet of gas burned.
			Sq.ft.		
1	Louisiana	2-table channel	0.21	4.87	3.75
2	do	1-table channel	.26	4.23	4.04
3	West Virginia	Roller		9.10	7.33
4	do	Large-plate		6.55	7.16
5	do	2-table channel		5.05	6.75
6	do	Small-disk		3.10	2.90
7	Oklahoma	1-table channel		3.70	3.50

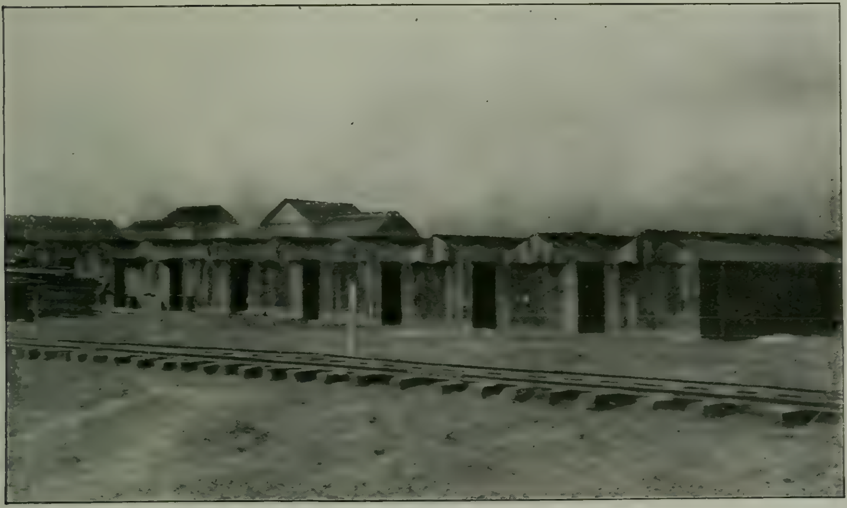
[a] Square feet of depositing surface.

VARIOUS FACTORS AFFECTING YIELD OF CARBON BLACK.

The various factors that affect the yield of carbon black are (1) the design of the plant, (2) weather conditions, (3) the pressure of the gas, and (4) the presence of salt water and oil in the gas. Factors of utmost importance in efficient recovery are the design of a plant, the kind of lava tip used, the distance from the depositing surface to the top of the lava tip, the arrangement for admitting air, and the rate of movement of the collecting surface. Provision should be made in construction for changing the height of burners, as different gases require different distances below the depositing surface. In West Virginia the lava tips are about 3 inches below the channels, but in Louisiana this distance is too great. By changing the position of the lava tips, one company in Louisiana increased its production of carbon black 20 per cent. If the tips are placed too near the collector, the flame tends to pass around the surface and loss of carbon black in flue gases increases. The rate of actuation of the depositing surface affects the quality of the carbon black manufactured more than it affects the quantity recovered. This factor, therefore, is determined by experiment; it is one of the flexible features, whereby various grades of black may be made by using the same method. The devices for admitting air are controlled by using as an index the color of the smoke issuing from the buildings, the superintendent having in mind the quality of black to be made and compensating losses in flue gas according to the quantity of black recovered.

Even at the most efficiently designed plant, the effects of weather conditions must be taken into consideration. A typical plant is

A. CARBON-BLACK PLANT EQUIPPED WITH WINDBREAK.



B. PLANT WHERE DRAFTS ARE CONTROLLED SO THAT LOSS OF FLOCCULENT CARBON IS AT A MINIMUM.

shown in Plate IX, *B*. Wind cuts down the yield by causing the flame to flicker and not lie quietly and smoothly against the surface of the iron. A company that was experiencing difficulty in obtaining efficient yields discovered its trouble was due to the sweep of the wind down a narrow valley toward the condenser building; the trouble was entirely eliminated by erecting a large wind break to protect the buildings, as shown in Plate X, *A*. (See also Plate X, *B*). Moist weather or light rains have little or no effect on the quality or the quantity of carbon black produced, but heavy rains tend to diminish the quantity and to injure the quality. Sometimes the water wets the black and cakes it, thus causing error in weighing the product in the packing room.

In considering the low recoveries of carbon black, persons not familiar with the industry usually think that relative efficiency may be increased merely by reducing the temperature of the collecting surfaces by means of air or water. G. L. Cabot,[10] for example, who has had a wide experience in cooling the surfaces on which carbon black is deposited, says on this point:

> The first factory that I ever owned, at Worthington, Pa., was originally built beginning in the year 1882, and carried water on the surface to keep the temperature down to the boiling point. We subsequently got much better yields without water cooling. Later on I tried the experiment of sprinkling the surfaces continuously with a lawn sprinkler device, and here again I immediately cut down the yield. Later on I bought a factory where black was condensed on hollow channels through which air was blown. We never were able to find that it perceptibly affected either the quality or quantity of black whether or not the air was blown through the channels.

Numerous difficulties on account of warping, expansion and contraction, corrosion, and rapid depreciation of equipment accompany the cooling of the depositing surface. The ordinary channel building when heated to the operation temperature expands 4 inches in a straight line; this expansion tends to force out of alignment the shafting, rack, gears, and other accessories. Expansion and contraction often warps the depositing irons to concave or convex surfaces and it then becomes difficult to remove the accumulated carbon; if the black is permitted to remain on the irons too long its quality is impaired by the formation of excessively heated gray particles called "grit." The forcing of air or water through or over the collecting surfaces leads to corrosion and increases depreciation. A 39-inch thermocouple inserted through the side of a carbon-black building, the stem projecting over the channel irons and about 10 inches above them, indicated, according to a standard pyrometer of the hot and cold junction type, that the temperatures of the different buildings varied from 650° F. to 800° F. The actual temperature of the channel ranged from 932° to 1,100° F.

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[10] Personal communication.

The records of the factory show conflicting reports on results obtained in extremely cold or hot weather. The personal element may possibly be the determining factor at this point. Low yields in excessively hot or cold weather may result from the effect of temperature upon the men operating the factories who may not maintain the efficiency of the apparatus rather than from the effect of temperature upon the physical and chemical reactions in the manufacturing process.

Hippolyt Kohler[11] makes the following statement regarding lamp black:

> It follows with positive certainty that cooling of the flame for the purpose of producing lamp black is not necessary, since carbon does not separate with a low temperature flame, but on the contrary with the right high temperature. An object put in a flame can serve for the most part only as a trench which catches the evolved globules of soot and its heat-conducting property affects the production of carbon only inasmuch as it prevents too much burning of the carbon liberated in the flame.

Undoubtedly whenever the depositing surface is cooled below the reacting temperature, some of the hydrocarbons in the flame escape undecomposed. The flame must be neither extremely cold nor excessively hot, else the gas will not be decomposed completely, or too much carbon will be burned. A surface that is too hot collects less carbon black than a colder one, but a surface that is too cold chills the flame and less carbon is liberated.

Recovery of gasoline from natural gas before utilizing the gas for manufacturing carbon black is a large source of revenue. Stripping the gas of the gasoline vapors has no appreciable effect on either the quality or quantity of the carbon black produced. Each tenth of a gallon of gasoline recovered from each thousand cubic feet of gas reduces the volume of the gas three-tenths of a per cent; hence gasoline recovery does not change appreciably the carbon content of even a rich dry gas.

If the absorption process is used in recovering the gasoline from the gas, the gas may carry some absorption oil into the carbon black building. This oil would lower the quality of the black by increasing the volatile constituents, and the collection of the oil in low points in pipe lines would result in a fire hazard by the shutting off of the gas supply in some of the buildings. This condition can be eliminated completely by using absorbers of adequate size and by installing efficient drips on the discharge gas from the gasoline plants.

The presence of salt-water gas and a large percentage of sulphur have similar effects on the operation of a carbon-black plant. Salt crystallizes, and sulphur compounds accumulate on the lava tips causing the flame to "fork" so that it is not distributed evenly over the depositing surface, and the volume of the gas passing through the burners is decreased. Where absorption gasoline plants are used in connection with carbon-black factories, difficulties from salt water are largely obliterated. If the flame becomes forked it is necessary to draw a thin knife through the tip and brush the "whiskers" from it. Some plants use only a brush to clean tips. In the Indiana gas field where the gas had a high sulphur content, the tips were cleaned every two weeks, whereas at some plants they are brushed but once a year.

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[11] Kohler, Hippolyt, Das Fabrikation des Ruszes und der Schwarze, p. 105.

The pressure of gas will in a measure affect not only the quality but also the quantity of the black produced. The pressure on distributing lines to burners varies from 0.2 inch to 1.5 inches water pressure. The use of kerosene or light lubricating oil in manometer tubes for determining pressure will eliminate in winter the trouble from water freezing in instruments exposed to the weather. With excessive pressures the yield of black usually is low.

SOURCES OTHER THAN NATURAL GAS FROM WHICH CARBON BLACK MAY BE MANUFACTURED.

Carbon black was first manufactured from artificial gas. The product is very glossy, has an intense color, and makes a high-priced printing ink. No black made from natural gas possesses all the qualities of that made from artificial gas. Carbon black, of course, could be manufactured from artificial, illuminating, blast furnace, producer, or coke-oven gases were it not for the prohibitive cost of the original gas. It has been made from coke-oven gas in England in recent years by Recketts & Sons, of Hull. Mr. G. L. Cabot says: "I have found illuminating gas and coke gas better than most natural gas for this purpose, except in price."

Several patents have been granted on processes in which carbon black is made by exploding mixtures of acetylene and air under pressure. The pressures vary from 50 to 100 pounds per square inch and the explosion shows that the acetylene is not merely oxidized but is dissociated. The acetylene is obtained from refuse calcium carbide—noncommercial grades too finely divided or having too low a content of carbide to be merchantable. Difficulties in this process are the rapid mechanical depreciation of the apparatus, the small output for invested capital, the inferior color and strength of the black compared with natural-gas black, and the uncertainty of the supply of refuse carbide. As it is a by-product, the price of commercial calcium carbide is prohibitive. Only a little black is made by this method, although the product is preferred for some purposes on account of its inherent bluish tinge. A small plant in Chicago burns acetylene, as in the manufacture of carbon black from natural gas. The collecting plate is cooled by circulating water with a rate of flow regulated by a thermostat. A yield of 11.6 pounds of black per thousand cubic feet of acetylene is obtained, which is a recovery of 17.3 per cent. Black made by burning acetylene is of better color than that made by explosion.

For some purposes, as for phonograph records, medical hard rubber, certain kinds of printers' ink, and black paint, it may be possible to substitute lampblack for carbon black, but for most purposes these two products are quite dissimilar in their physical properties and to date have proved unsuitable for substitution.

FIRE HAZARDS ACCOMPANYING THE HANDLING OF CARBON BLACK.

About 1890 a barrel of black shipped from a plant in Pennsylvania carried with it a spark of fire that entirely consumed the black and charred the lining of paper, but did not affect the barrel. Only two fires have occurred recently while carbon black was being transported. One was in 1914 at Baltimore, Md., in a car containing 200 wooden barrels of black; it resulted in the destruction of the car and contents, entailing a loss of $1,185. The other fire was in 1918, in a car loaded with 19,000 paper bags, each containing 12½ pounds of carbon black. The car was damaged only slightly, but the contents were entirely destroyed, resulting in a financial loss of $2,875.

G. L. Cabot [12] says, "these unexpected conflagrations led to the erroneous charge that carbon black is subject to spontaneous combustion."

The following experiment [13] was carried out: A water-jacketed oven was packed closely with carbon black and heated to a temperature of 100° C. for 72 hours without the temperature of the contents rising above 100° C. From this test and similar ones it is concluded that carbon black is not subject to spontaneous ignition.

A sample of carbon black was compressed, cooled to 0° C., and a vacuum pump applied. The gas liberated upon heating showed the following analysis:

Gases from carbon black.

	Per cent.
Carbon dioxide	0.32
Oxygen	21.20
Nitrogen	76.48

The ultimate analysis of another sample gave the following results:

Ultimate analysis of gas from carbon black.

	Per cent.
Hydrogen	0.5
Carbon	96.76
Nitrogen	.01
Oxygen	1.61
Sulphur	.12
Ash	.24

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[12] Personal correspondence.

[13] Communication with Col. B. W. Dunn and C. P. Beistle, Bureau of Explosives.

It is evident that oxygen is selectively adsorbed and the slow mouldering of a spark in carbon black is due in a large measure to the occlusion of oxygen.

COST DATA.

The cost of constructing a carbon-black plant is usually given in dollars per barrel of fifty pounds of black. Previous to the war, a plant using the channel process could be constructed for $1,000 per barrel, but this figure has increased to $1,500 to $3,000 per barrel, depending on the size and the location of the factory. The following table gives construction costs of factories using the channel method:

TABLE 8.—*Cost of construction of channel plants.*

Date built.	Cost.	Capacity, pounds per day.	Cost, dollars per barrel.
1913	$116,000	6,000	$966
1916	40,000	1,000	2,000
1916	110,000	2,600	2,115
1917	608,000	19,000	1,600
1919	125,000	2,000	3,125

The cost of construction of a plant using the rotating-disk process is only slightly greater than that of a channel plant. No data are available on cost of erection of either roller or large-plate carbon-black plants.

The cost of operation, not including cost of gas, varies from 98 cents to $2 per hundred pounds of carbon black produced. This takes into account labor, sacking and resacking, depreciation, supplies, and repairs. The labor costs are notably low because most of the work is performed automatically by machinery. Table 9 shows the number of men employed at some of the plants:

TABLE 9.—*Comparison of number of men employed in different types of plants.*

Daily production.	Process.	Number of men employed.	Daily production per men employed.
Pounds.			*Pounds.*
2,600	Channel	7	371
1,000	Channel	4	250
6,000	Rotating-disk	13	461
300	Roller	3	100
12,000	Channel	16	750
8,000	Plate	18	440

The cost of gas ranges from 1.5 cents to 6½ cents per thousand cubic feet of gas, and is the largest expense and the most uncertain factor in the carbon-black industry. Most of the companies charge

10 per cent a year to depreciation, although one company charges off 12.8 per cent. This figure assumes to cover the hazard in the supply of gas. Depreciation of machinery is surprisingly small.

FUTURE PROSPECT OF INDUSTRY.

Attempts are made periodically to increase efficiency in the recovery of carbon black by enriching the gas with oil vapors. The amount of oil vapor held by the gas will depend upon (1) the relative temperature of the oil and gas, (2) the mechanical arrangement for bringing the oil and gas in contact with each other, and (3) the properties of the oil used. The oil usually employed is fuel or gas oil and ranges in gravity from 28° B. to 38° B. The oil vapor makes the color of the resulting product less intense, although the difference is not great enough to diminish the value of the black. It is doubtful whether this procedure is a commercial possibility or can be made profitable, especially as the field for the utilization of fuel oil is being so rapidly extended and its value trending upward.

The addition of chlorine to the burning gas has been tried in the laboratory, with the object of increasing the yield by the formation of hydrochloric acid and the liberation of carbon. The increased yield has not yet proved compensatory with the increased cost of apparatus and operation. One difficulty lies in the rapid deterioration of apparatus.

It is possible to augment the yield by catching the black that escapes from the condensing units, although the product that floats away in the air is relatively unimportant in bulk. Escaping black possesses an extremely low apparent specific gravity as compared with that deposited upon the irons. It may possibly have properties that would make its application especially useful for some purpose, but it resembles an inferior grade of lampblack and not carbon black. Undoubtedly this product could be collected by electrical precipitation. One company is installing a flue dust collector of the filter type. The yield of carbon black can be increased by diminishing the supply of air and by controlling the draft (see Pl. X, *B*), but the quality of the product is impaired. The maker of carbon black must work within a narrow range to obtain the best average results. Generally a burner that gives a heavy deposition of black on the cooling surface also increases the amount of black carried away in the flue gases.

Probably the most beneficial line of improvement of present commercial methods lies in changing the design of the plants so that the cost of construction will be diminished. The control of the supply of air should be regulated more efficiently and provision should be made in the design to render plants independent of weather conditions, especially of winds.

Thermal decomposition probably offers tne most promising method of increasing the quality of black from natural gas. The present methods are destructive to the apparatus—a defect that undoubtedly can be overcome—and the resultant product contains grit or adamantine carbon, is grayish, and contains some volatile matter.

ECONOMICS OF CARBON-BLACK INDUSTRY.

It is generally conceded that the most important use that can be made of natural gas is for domestic purposes. Whether gas is of greater economic value for the manufacture of carbon black than for other industrial purposes is a question that will depend on the conditions existing in each locality where a large supply of natural gas is available.

The policy of the Bureau of Mines in this regard is stated in Paragraph 34 of the resolutions adopted by the National Committee on Natural Gas Conservation, June 11, 1920, which reads:

> *Resolved:* That carbon black be made when gas is produced in isolated sections with no present or reasonably prospective market for gas being produced, when gasoline has been extracted, and when practical and modern and improved methods are used.

At present there is considerable agitation for and against laws restricting the use of natural gas for the manufacture of carbon black. On February 24, 1919, the State of Wyoming enacted a law entitled "An Act for production and conservation of the supply of natural gas of the State of Wyoming prohibiting the waste and wasteful use of natural gas through the burning or consumption thereof for the manufacturing or producing of carbon or other resultant products therefrom, prohibiting the taking, using, sale, or other disposition of natural gas from gas wells for such purposes, and providing penalties for the violation of such Act." This law was still in force in 1920, having been held constitutional by the United States Supreme Court. The carbon-black industry has been established in Pennsylvania for over forty years, and in West Virginia for more than twenty years. The latter State still produces more than fifty per cent of the entire supply.[13] Neither of these States has ever passed any laws restricting the use of natural gas for this purpose.

During the past three years a number of carbon plants have been moved from West Virginia to Louisiana. The State authorities of Louisiana became alarmed at the situation and enacted a law[14] regulating the use of natural gas in industries. The Louisiana act does not prohibit the use of natural gas in making carbon black, and embodies essentially the following points: It shall be unlawful to permit the waste of natural gas, or to use natural gas for any purpose whatsoever in such manner as will threaten with premature exhaustion, extinction, or destruction the common supply or common reservoir from which natural gas is drawn.

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[13] U. S. Geol. Survey, Carbon black in 1920.

[14] Thompson, J. W., Petroleum laws of all America: Bull. 206, Bureau of Mines, 1921, p. 645.

The term waste as above used, in addition to its ordinary meaning, shall include:

1. Wantonly or willfully permitting the escape of natural gas in commercial quantities into the open air.
2. The intentional drowning with water of a gas stratum capable of producing gas in commercial quantities.
3. Underground waste.
4. Permitting any natural gas well to burn wastefully.

Additional information on the State laws dealing with conservation and use of natural gas may be found in Bulletin 206, Bureau of Mines.

The arguments most frequently heard against the use of natural gas for the manufacture of carbon black are: 1. Using natural gas for carbon black is depriving or will deprive domestic consumers of a supply; 2. Compared with other industries the industry uses an undue proportion of gas; 3. the value and the utility of carbon black are less than those obtainable by using the gas in other ways; 4. The methods used are carelessly inefficient and more efficient methods are at present available; 5. Utilizing gas for making carbon black threatens premature exhaustion of gas reservoirs.

On the other hand the carbon-black manufacturers claim that they use the best manufacturing processes that have been developed and that they produce a commodity of acknowledged utility. They have also provided a market for gas in isolated regions and in so doing have many times prevented conditions that would otherwise have resulted in waste. In certain isolated districts they have furnished small communities with natural gas whose consumption they assert was not sufficient to warrant the building of a pipe-line system.

The right of the domestic consumer to demand preference in the matter of the natural gas supply is not to be contested and where possible gas should be so utilized.

In view of the fact that carbon-black plants are ordinarily situated in the heart of gas fields, that the quantity of gas consumed is relatively constant throughout the year, and the pressure on the mains low, the amount of natural gas actually delivered to the carbon-black plant compares favorably with the amount actually delivered to domestic or industrial consumers where gas must be transmitted over long distances and under high pressures.

The value and utility of natural gas for carbon-black manufacture as compared to other uses depends almost entirely upon the local conditions surrounding the gas fields. For instance, if the gas burned for carbon black in Louisiana could be supplied to domestic consumers in Omaha, Nebr., or St. Paul, Minn., its exchange value would be greater than the carbon black made from it, and consequently if this exchange value was effective in the Louisiana field, the price of carbon black would either be commensurately increased or the manufacturers would automatically be forced out of the district by the prohibitive price they would have to pay for the gas. "The price is the universal barometer that indicates the changes in the demand for goods of all kinds."[15] Carbon-black plants operate until the price of gas rises on account of the supply being made available for domestic consumption by the construction or extension of pipe lines. Then the factories are dismantled and removed to more remote districts that have no other means for disposing of the gas. Thus the industry is necessarily migratory.

It is evident that location, in relation to market for gas for domestic and industrial consumption, is the largest economic factor affecting the value of gas and the carbon-black industry. This is true of a large number of our raw resources, such as coal in isolated districts in West Virginia, sand around the Great Lakes, or lumber in various districts of the Northwest.

Consumers of natural gas live in the gas-producing districts or at a reasonable distance therefrom, whereas users of carbon black are widely distributed. Consequently there is a conflict in interests between those who are in the radius of gas service from the field and those living a considerable distance from the field and benefiting by the use of carbon black.

The actual financial return accruing from the gas burned for carbon is usually larger than that from the sale of gas for industrial consumption from the same field. In Monroe, La., for example, gas is produced, piped, and delivered to the larger industrial users at a rate of 5 cents per thousand cubic feet. The carbon manufacturers pay 2 cents per thousand, and obtain from each thousand feet approximately one pound of carbon black, which sells for 8 cents per pound. Pipe-line companies because of a tenfold larger investment, unfavorable transportation conditions, such as high pressure and consequent leakage in the mains and the need for transportation facilities capable of handling gas during the period of maximum consumption, may find themselves at a disadvantage as compared to the carbon companies. The duration of the period of maximum consumption is probably only two weeks in the South, four months in Oklahoma, and six months in the East. Thus a gas distribution company in the eastern States must install equipment that is used only half of the time.

One gas concern in the Mid-Continent field delivers only 49 per cent of the gas collected in the field to the meter of the ultimate domestic consumer. Four per cent is used to operate compressors, 4 per cent goes to main-line consumers, 10 per cent to main-line loss, and 33 per cent is lost in distributing plants. Mr. G. E. Taylor, assistant engineer of the public service commission of West Virginia, estimates that the loss by leakage in transporting gas in that State ranges from 5 to 30 per cent. Some authorities declare that the annual loss of natural gas from leakage is equal to the annual consumption.[16]

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[15] Ely, R. T., Outline of economics, 1916, p. 29.

Three of the large industrial consumers of natural gas are zinc smelters, brick plants, and glass factories; Tables 10, 11, and 12 show the cost of gas and other factors of each of these.

TABLE 10.—*Value of gas used in manufacture of bricks.*

Brick plants, No.—	Quantity of gas used a day.	Cost of gas per M.	Bricks made a day, M.	Gas per M bricks.	Cost of gas per M bricks.
	M cubic feet.			*m.*	
1	1,000	$0.10	50	20	$2.00
2	860	.17	43	20	3.50

TABLE 11.—*Value of gas used by zinc smelters.*

Smelters, No.—	Quantity of gas a day.	Cost of gas per M.	Amount of spelter refracted a day.	Gas per pound of spelter.	Cost of gas per pound of spelter.	Spelter per M cubic feet of gas.
	M cubic feet.	*Cents.*	*Pounds.*	*Cubic feet.*	*Cents.*	*Pounds.*
1	6,500	8	110,000	60	0.48	16.6
2	3,625	11	69,059	53	.58	18.9
3	3,000	8	48,500	63	.50	16.0
4	2,760	4	60,000	46	.19	21.7
5	2,530	8	76,900	33	.26	30.3
6	1,442	10	28,400	51	.51	19.7
7	5,400	11	102,000	53	.58	18.8
8	5,100	11	108,000	47	.52	21.3
Average				50.7	.45	20.4

TABLE 12.—*Value of gas used in manufacture of window glass.*

Glass factories, No.—	Gas used weekly.	Cost of gas per M cubic feet.	Boxes [a] of glass per week.	Gas per box of glass.	Cost of gas per box of glass manufactured.	Glass per M of gas.
	M cubic feet.	*Cents.*		*Cubic feet.*	*Cents.*	*Boxes.*
1	7,700	10	3,335	2,320	23	0.43
2	13,500	11.6	6,000	2,250	26	.45
3	8,400	12.5	3,600	2,340	29	.43
4	8,500	13.5	3,000	2,840	38	.35

[a] Each box contains 50 square feet of glass having an average current value of $5.

Carbon black enters into the manufacture of printer's ink, automobile tires, paint, and other commodities and at present has no substitute. It is an economic good and possesses utility. It has been said[17] that the fast-feeding newspaper printing press of to-day has been made possible only through the use of carbon black in the making of long inks. It would be improper to claim that carbon black is less useful than zinc, glass, or brick, as each serves a definite purpose and each is essential and necessary for certain specific uses.

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[16] Wyer, S. S., Kansas Natural Gas Co. report.

In engineering, relative efficiency is really a comparison to an ideal or perfect standard. A perfect steam engine would be one that converted all of the energy latent in the coal used as fuel into mechanical power. The best steam engines, however, seldom convert more than 18 per cent of this energy, and the fuel efficiency of many steam engines is often as low as 1 per cent. Internal combustion engines using gasoline as fuel utilize approximately 20 per cent[18] of the total energy, as useful work, 35.8 per cent is lost in the cooling water, and 35.6 per cent is lost in exhaust gas and direct radiation of heat. The relatively low efficiency, 2.5 percentage of recovery, of present methods of producing carbon black is due to the waste of the resulting heat. In some districts, however, as in the Kanawha Valley of West Virginia, it might be feasible to utilize this heat in the evaporation of brines that yield sodium chloride and bromine. One company is doing some experimental work on dehydrating fruits and vegetables by the waste heat; such heat might be transformed into electrical energy for areas within carrying distance of the plants or might be used to electrify short railways.

It is pertinent that thus far the production of carbon black by thermal decomposition has given a product that can be utilized only in the making of cheap paints, and has sold as low as 2 cents per pound. As made by present methods it does not possess the valuable properties of the black made by the channel system, or by other commercial carbon-black processes. Inasmuch as the market for carbon black is more or less limited, it is obvious that if any process yielding 7 or 8 pounds of black per thousand cubic feet of gas by simple thermal decomposition can be made available, the older methods of manufacture will be abandoned.

Carbon-black factories utilize gas from low-pressure wells, casing-head gas from which the gasoline content has been removed, and gas that would otherwise be wasted. Formerly in Oklahoma one gas company broke its well connections when the rock pressure of the well decreased to 150 pounds. This is an exceptionally high pressure for abandoning a gas well. It should be mentioned, however, that gas at this pressure could easily be used in making carbon black as only a fraction of a pound pressure is necessary at the plant. In several localities gas is liberated into the atmosphere after the gasoline vapor has been extracted. It would seem possible in such localities to utilize the residual gas for carbon-black manufacture with reasonable confidence of a fair profit. Formerly, in developing a new territory the search was primarily for petroleum and a strike of gas was considered next to a failure, particularly if the district were remote from industrial centers. In such districts, the selling of gas to carbon-black manufacturers is entirely justifiable and may furnish the needed capital to continue drilling. Utilizing gas from such sources is really a measure of conservation.

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[17] Personal statement of A. E. Whiting, Shreveport, La.

[18] Stratford, C. W., Veedol, 1918, p. 8.

WHY CARBON-BLACK MANUFACTURE ATTRACTS CAPITAL.

The manufacture of carbon black from natural gas is more inviting in some localities than the use of the gas for public utility service, for the reason that low pressure gas can be utilized, extensive transmission lines are unnecessary, the load is uniform, the field is near and installation is more elastic or is capable of being moved to another locality, and the necessary investment is smaller.

By utilizing low-pressure gas, the ultimate production of wells would be greater and wells with smaller potential capacities would be used; the line leakage would be smaller and the pipes to the gathering lines would cost less than high-pressure fittings and pipe connections. The gas utility company, on the other hand, would be forced to make an additional investment to install compressors, as it would require artificial pressure to transport low-pressure gas to the consumer.

Carbon-black factories are situated in the field or near the producing leases, so that only collecting lines to the wells are used; these lines are usually very short, and no compressors or high pressures are required. In consequence the cost of pipe is much less than with gas companies. A carbon-black plant uses approximately the same quantity of gas every day in the year, and hence can use its total equipment all the time. It can be situated in isolated fields where market facilities for other purposes are not available and consequently can obtain gas at lower rates. As mentioned before, a gas plant operating as a public utility can use its total equipment only during peak-load periods and is using its total capital only a fraction of the time.

Inasmuch as pipe-line investment covers chiefly gathering lines and the factories are of standard design and easily dismantled, a carbon-black plant can be moved from place to place with much more ease and less expense than can the equipment and installations of a natural-gas utility company. Large gas companies incur much of the initial expense in laying trunk lines, and when a gas field becomes depleted the expense of transferring the equipment to another field is much greater than for carbon-black plants. The hazards due to depletion of the gas supply are consequently less than for a public utility plant.

The investment necessary for each thousand cubic feet of gas handled will be about ten times[20] larger in a public utility plant than in a carbon-black factory. Carbon-black manufacturers do not carry a large reserve acreage, and hence need less capital. The investment necessary for transporting natural gas is greater than for any other utility service, assuming that the gas is collected in the field and delivered to the domestic consumer's meter. The cost is 50 per cent [21] greater than for ordinary manufacturing plants, and 300 per cent more than for electric plants.

SUMMARY.

The utilization in the manufacture of carbon black of low-pressure gas, of gas escaping into the air from natural-gas gasoline plants, gas in distinctly isolated districts, and gas in fields that have been abandoned by other gas companies on account of low pressure, is in reality often a conservation measure. It is preferable to the practice of letting the gas go to waste in the air or to plugging improperly the wells so that the gas sands can be damaged from flooding by water.

At present there is no more efficient process of making a product that has the properties of carbon black other than those methods described in the following pages. Thermal decomposition offers an interesting field for research as a possible means of increasing the relative efficiency of the industry. In the future it is probable that at some plants the waste heat will be utilized profitably.

Sufficient incentive to enterprise must be provided; to keep the gas in the ground for an indefinite period ties up money and resources. If the gas can be utilized and made to yield good to the State and profit to the individual, the public benefits accordingly, whereas if the gas remains in the ground where it can not be used and gives no returns on the investment, the loss to the State and to the individual may be gaged by the interest lost during the period of no returns. The question always arises whether it will in the end pay to hold the gas in the ground awaiting an unknown future period of use that will give greater returns than the present methods of utilization. Local conditions are the determining factor.

Probably the most beneficial use that can be made of gas is for domestic consumption and the Bureau of Mines does not recommend that gas be used for the manufacture of carbon black where an adequate market for the gas for domestic purposes is available.

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[20] S. S. Wyer, Natural gas, its production, service, and conservation: U. S. National Museum, Bull. 102, 1918, p. 61.

[21] West, F. H., Sale of natural gas carbon-black increasing: Gas Age, Dec. 16, 1918, p. 536.

PART II. CARBON BLACK—ITS PROPERTIES AND USES.

By G. St. J. Perrott.

INTRODUCTION.

The Bureau of Mines undertook an investigation of the carbon black industry as a result of economic issues arising during the World War. In the present methods of manufacture, carbon black is made by burning natural gas with a luminous flame against a metal surface and then collecting the liberated soot. This process produces from ½ pound to 2 pounds of black per 1,000 cubic feet of gas, or 1.5 per cent to 6.5 per cent of the total carbon in the gas. As the industry consumes about 40,000,000,000 cubic feet of gas annually, it seemed during the war that this seemingly wasteful utilization should be restricted and the gas saved to other industrial plants or to domestic consumers.

Little information was available, however, as to the methods of manufacture of carbon black, as to the feasibility of improving the existing methods, of substituting other more efficient methods for producing carbon black from natural gas, or of making it from some entirely different raw material. Data were needed also in regard to the industries using carbon black—how essential carbon black was to the various consumers, and which users could employ a substitute material.

In the spring of 1919 the Bureau of Mines began an investigation of the manufacture, properties, and uses of carbon black. Plants in Louisiana, Oklahoma, and West Virginia were studied by engineers of the bureau. Other processes for making carbon black were investigated, test methods studied, and microscopic and chemical analyses of a large number of blacks were made to explain the differences in behavior of different blacks.

This paper deals with the chemistry of the present methods of making carbon black, considers the possibilities of producing it by other methods, and describes in some detail the properties and uses of the product. The first part of this publication, by R. O. Neal, describes the design of plants for the present method of manufacture and discusses the economic aspects of the industry.

ACKNOWLEDGMENTS.

The writer wishes to express his appreciation of the valuable assistance and suggestions of A. C. Fieldner, supervising chemist, under whose supervision the work was carried out, and of the assistance of J. O. Lewis, chief petroleum technologist of the Bureau of Mines, and R. O. Neal, chemical engineer in the Bureau of Mines, who made it possible for the writer to visit carbon-black plants in Oklahoma and West Virginia.

Acknowledgment is made of the helpful cooperation of the following individuals and companies:

Binney & Smith, New York City, through whose courtesy several plants of the Columbian Carbon Co. in West Virginia were inspected, and who furnished information as to the uses of carbon black and samples of various blacks.

G. L. Cabot, Boston, Mass., who freely gave much valuable information, and who furnished gratis large amounts of different grades of carbon black.

G. H. Morrill Co., Norwood, Mass., who gave information as to testing methods and uses of carbon black, and furnished samples of black and printing ink.

J. V. Bassett, Hewitt Rubber Co., Buffalo, N. Y., who furnished information in regard to the use of carbon black in rubber, and samples of rubber articles containing carbon black.

J. P. Coe, U. S. Rubber Co., New York City, who furnished statistics in regard to the use of carbon black in the rubber industry.

Norman Underwood, Bureau of Engraving and Printing, Washington, D. C., who furnished information as to the uses of carbon black in the ink trade.

Acknowledgment is also made of the cooperation of the following individuals and companies: Dr. J. B. Garner, Mellon Institute, Pittsburgh, Pa.; Henry A. Gardner, Washington, D. C.; W. C. Robinson and J. V. Pogue, Fuel Administration, Washington, D. C.; Jaenecke-Ault Co., Newark, N. J.; Kee Lox Manufacturing Co., Rochester, N. Y.; Carter's Ink Co., Boston, Mass.; Aeolian Co., Meriden, Conn.; California Leather Dressing Co., San Francisco, Calif.; Columbia Graphophone Co., New York City; Mittag & Volger, Park Ridge, N. J.; Remington Typewriter Co., New York City; Sinclair & Valentine, New York City; California Ink Co., San Francisco, Calif.; Dunn Ink Works, Buffalo, N. Y.; American Printing Ink Co., Chicago, Ill.; Philip Ruxton Co. (Inc.), New York City; Standard Printing Ink Co., Cincinnati, Ohio; Queen City Printing Ink Co., Cincinnati, Ohio; Buffalo Printing Ink Works, Buffalo, N. Y.; F. H. Levey, New York City; H. S. Prescott, Boston, Mass.; Fuchs & Lang Manufacturing Co., New York City; General Manifold & Printing Co., Franklin, Pa.; W. T. Rawleigh Co., Freeport, Ill.; S. M. Bixby & Co., Brooklyn, N. Y.

PRESENT METHODS OF MANUFACTURE.

Carbon black, as known to the American trade, is the fluffy, velvety-black pigment produced by burning natural gas with a smoky flame against a metal surface. In its physical characteristics it is entirely different from lampblack, which is made by burning oil or other carbonaceous material with insufficient air and collecting the smoke in settling chambers. Lampblack is gray in contrast to the deep black of carbon black, it often contains considerable quantities of empyreumatic matter, and a printing ink made from it has very different properties from one of similar composition made from carbon black. The process of manufacture most widely used at present is the so-called channel system, in which the black is deposited on the smooth undersurface of steel channels by lava-tip burners. The channel irons are usually built into tables of eight, sometimes 100 feet long. They are given a slow reciprocating motion that scrapes the black deposited on them into hoppers, from which it is carried by screw conveyors to the packing house, and there bolted and sacked.

The mechanism is inclosed in sheet-iron buildings in order that the amount of air may be regulated. Variation in the amount of air, in the speed of scraping, and in the pressure of the gas controls the quality of the product. The shape of the burner and the distance from the collecting surface also affect the quality of the black, but these factors are constant for any one plant. Other similar processes differ only in the nature of the collecting surface and the burners. G. L. Cabot, a pioneer in the manufacture of carbon black, has described the development of the industry.[22]

THEORY OF FORMATION OF CARBON BLACK.

When natural gas burns in an incomplete supply of air, the carbon is liberated not as a result of preferential combustion of hydrogen but as a direct decomposition of nuburned gas in the heat of the flame. According to Bone [23] and his coworkers, combustion takes place in steps as a result of hydroxylation:

$$\begin{tikzcd}[column sep=huge, row sep=large]
\text{A} & \text{B} & \text{C} \\
CH_4 \arrow[r, "\text{Oxidation}", "+30"'] \arrow[d, "\text{Decomposition}"', "-22.7"] & H_3:C.OH \arrow[r, "\text{Oxidation via } H_2:C:(OH)_2", "+50"'] \arrow[d, "\text{Decomposition}"', "-22.8"] & H_2:C:O+H_2O \arrow[d, "\text{Decomposition}"', "-13.4"] \\
C+2H_2 & CO+2H_2 & CO+H_2 \\
\text{A}' & \text{B}' & \text{C}'
\end{tikzcd}$$

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[22] Cabot, G. L., Carbon black and lampblack: 8th Int. Cong. Applied Chem., vol. 12, 1912, p. 13.

[23] Bone, W. A., Gaseous combustion: Phil. Trans. Roy. Soc. London., vol. 215, 1915, pp. 275-315.

It is evident that the tendency is always to run from A to C. When the proportion of methane to oxygen is $CH_4 + O_2$ the reaction goes from A to B to C to C′. If the ratio is $2CH_4 + O_2$ or higher, only a part of the methane can be oxidized through the reaction A to C and part is decomposed at A by the heat evolved in the A to C reaction. The lowest per cent of oxygen in which a methane flame will burn is 15.6 per cent. Only in the inner part of the flame where the oxygen supply is low but where there is enough heat to break up the methane will carbon be evolved, and the percentage of carbon to be had by the incomplete combustion of methane is low; gases rich in ethane and the higher homologs give greater yields of carbon. Bone[24] in his experiments on the explosive combustion of hydrocarbons noted that the decomposition of methane was a surface effect and produced a hard gritty carbon, but the decomposition of ethane, ethylene, etc., took place throughout the whole mass of the gas and gave a soft carbon.

The function of the cold surface is to cool the liberated carbon in the flame enough to prevent its combustion. This procedure allows of a sufficiently hot flame to give carbon uncontaminated with empyreumatic matter, and produces a finely divided material which has been prevented from agglomerating by the sudden cooling. It is evident there must be an optimum temperature and an optimum position for the surface in the flame. Too cold a surface may prevent the maximum separation of carbon; too hot a surface will allow too much carbon to be burnt and may change the properties of the carbon that remains unburnt. The temperature of the channels in the present process is about 500° C.

The air supply must be regulated carefully. Admission of too much air will cause too large a percentage of the carbon to be burned in the flame and may even burn part of the carbon on the surface after it has been liberated. Insufficient air will give too cool a flame for the maximum yield of carbon and will produce a carbon contaminated with adsorbed intermediate products of combustion, as more of these intermediate products result at the lower temperature and as carbon has a greater power of adsorption at the lower temperature. The presence of these adsorbed impurities in carbon black for making ink is often desirable, the ink being of greater length than that from carbon blacks that are purer; hence manufacturers often sacrifice a high yield of black in order to obtain a product containing more volatile matter. This point is, on a later page, discussed in connection with the microscopic analysis of carbon blacks.

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[24] Bone, W. A., Gaseous combustion: Phil. Trans. Roy. Soc. London, vol. 215, 1915, pp. 275–315.

OTHER METHODS OF MAKING CARBON.

Numerous methods for producing a larger yield of carbon from natural gas have been patented. In most of them the gas is broken up into carbon and hydrogen by passing through a retort filled with refractory material at a temperature of 1,200° C. or over. A much higher yield of carbon is produced in this way, sometimes as high as 40 per cent of the theoretical yield, but a salable grade has not yet been made on a large scale by this means.

PATENTS.

McTighe, United States patent 346,168, passes hydrocarbon vapor through a heated retort, decomposing the gas into flocculent carbon which is separated in depositing chambers.

Purtle and Rowland, United States patent 866,883, pass hydrocarbon gas at 10 pounds pressure into a closed retort heated to 800° C. and periodically remove the deposited carbon by means of a scraper.

Snee, United States patent 1,036,362, decomposes hydrocarbon gas in a retort heated electrically to 1,300 to 1,800° C. and deposits the liberated carbon on the bottom of the retort which is kept at a relatively lower temperature, thus preventing the coking of the carbon which occurs when the carbon deposits on surfaces heated to a high temperature.

Fernekes, United States patent 1,066,894, produces lampblack free from impurities such as naphthalene by passing methane through an alundum tube heated electrically to about 1,700° C. The gas is decomposed into carbon and hydrogen without formation of intermediate products.

Szarvasy, United States patent 1,199,220, produces retort carbon from methane by passing the gas over particles of carbon heated to glowing temperature. The necessary temperature is maintained by supplying hydrogen and air or oxygen before introducing the methane.

Brownlee and Uhlinger, United States patents 1,168,931 and 1,265,043, produce carbon black and hydrogen by passing natural gas or other hydrocarbon under pressure through a tower containing highly heated refractory material. The material is heated by surface combustion, air being intermittently added to the gas.

Bacon, Brooks, and Clark, United States patent 1,220,391, pass a hydrocarbon through a tube made up of graphite rings heated electrically to a temperature above 1,200° C. Carbon black and hydrogen are produced simultaneously and the gas pressure developed removes the carbon while still in suspension in the hydrogen.

McCourt and Ellis, United States patent 1,276,385, produce gas black and hydrogen by passing methane through a highly heated bed of granular refractory material at sufficient speed to prevent deposition of carbon on the refractory material. The treating tube filled with refractory material is surrounded by a heating tube containing refractory material that is heated by surface combustion of the hydrogen produced in the process.

Garner [25] claims to make a good grade of carbon black from natural gas, obtaining several times the yield of the present process presumably by cracking the gas in presence of a catalyst. Other proposed methods of making carbon black from natural gas are chlorination to hydrochloric acid and carbon (Mott, U. S. 1,259,121; Averill, U. S. 1,238,734), explosion at elevated temperature, and pressure with a "priming charge" of acetylene (Machtolf, U. S. 872,949), explosion with CO or CO_2 (Gollmert, German patent No. 212,202, Nov. 1, 1907), and electrical deposition of lampblack from a flame on a wire screen (Thieme, German patent No. 256,675, Jan. 11, 1912).

Several patents have been granted for making carbon black by the explosion or thermal decomposition of acetylene (Morehead, U. S., 779,728, 986,489; Pictet, British, 24,256, Oct. 19, 1910; Wegelin, German, 201,262, Jan. 9, 1907; Bosch, German, 270,199, Feb. 8, 1913), and in Europe considerable quantities of black were made from acetylene from carbide waste. This black is said to have a bluish tinge, to be very free from impurities, and to be of considerable value in making certain kinds of ink. No quantity of black made by this process has ever been on the American market.

Other patents describe the manufacture of carbon black from hull bran (Hershman, U. S., 1,188,936); from peat (Smith, U. S., 916,049); by incomplete combustion of petroleum vapor in a closed chamber (Frost and Nix, U. S., 977,000); from coal tar by treatment with alkali and naphtha (Evans, U. S., 1,175,732; French, 480,487, Aug. 9, 1916; German, 291,727, Feb. 3, 1914); from oil by decomposing a thin film on a disk by playing upon it an electric arc or gas flame (British, 124,557, Mar. 22, 1918); by reducing CO or CO_2 over finely divided carbon (Tamp, Canadian, 175,937, Mar. 27, 1917).

DISCUSSION OF POSSIBLE SUBSTITUTE METHODS.

The process of Brownlee and Uhlinger has been put into commercial operation for producing hydrogen, but thus far no market has been found for the carbon produced, which is usually gray and contains particles of grit that may be agglomerates of carbon or may be particles of the refractory material. It seems highly possible, however, that carbon suitable for use in rubber might be made by this method, or better, by a modification of the method in accordance with the ideas expressed in the patents of Snee and of Bacon, Brooks, and Clark. The ink makers would be harder to satisfy.

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[25] Garner, J. B., The chemical possibilities of natural gas: Proc. Nat. Gas Assoc. of America, vol. 10, 1918, pp. 136–169.

The carbon after being formed must not be allowed to stay in the heated zone long enough to become agglomerated and changed into the gray variety of amorphous carbon. In the method of Snee a cold surface is provided for collecting the carbon immediately after liberation, while Bacon, Brooks, and Clark rely on the rapid expansion of the decomposing gases to sweep the carbon out of the hot zone.

It seems probable that a raw material of simple composition, such as natural gas or a pure organic substance, will be more susceptible of decomposition to a good grade of carbon black than a complex mixer, such as tar oil or crude petroleum. The difference between carbon black and ordinary lampblack may be due partly to the fact that lampblack is made from a complex mixture of compounds each with its own optimum temperature of decomposition. A uniform product from such a mixture is less likely to be expected than from a simpler raw material.

Explosion of hydrocarbon vapors with CO, CO_2, O_2 or their mixtures might be worthy of investigation, and there is a possibility of utilizing the gases from oil-cracking processes.

Microscopic examination of carbon black shows that the particles are smaller than 0.2 microns. It is hardly possible to hope to approach any such fineness of subdivision by grinding charcoal or other carbonaceous material. G. A. Hulett,[26] in experiments on the true density of charcoal, ground coconut charcoal in a ball mill through which a slow current, about 5 c. c. per minute, of air was passing. The fine dust carried along with the air was precipitated electrically. A sample of it showed only one-third the tinting strength of carbon black, although the true density of the ground charcoal was but 5 per cent greater.

At present most substitute processes of manufacture are impracticable for economic reasons. As carbon black in 1920 sold as low as 9 cents a pound, it is cheaper than ordinary lampblack. The author knows of no process that has produced on a commercial scale a product with properties similar to those of the carbon black now being made.

Probably the most promising line of attack in the search for a substitute process is the cracking of gas or oil in a heated retort provided with suitable means for getting the liberated carbon away from the heated zone immediately after liberation. If such a process were perfected to make a satisfactory carbon black, the material could be sold at a low price on account of the large yield and the value of the hydrogen produced. The hydrogen may be compressed in tanks and used for cutting flames, or for the hydrogenation of oils. This process is one of the cheapest ways of producing hydrogen for the latter purpose. It might be impracticable to make use of the hydrogen on account of difficulties in transportation, but the black could still be made at least as cheaply as at present if engineering difficulties could be overcome.

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[26] Private communication.

USES OF CARBON BLACK.

The uses of carbon black, in the order of their importance, are as follows: (1) Printer's ink, (2) rubber, (3) black and gray paint and enamel, (4) stove polish, (5) other products such as phonograph records, carbon paper, crayons, typewriter ribbons, black and gray paper, glazed paper, tarpaulins, black leather, bookbinders' board, marking and stenciling inks, rubber sheeting and clothing, hard rubber, artificial stone, and black tile, Chinese and india inks, insulating materials, and case hardening. The amounts used by these industries during 1918 were approximately as follows: Printer's ink, 10,000,000 to 12,000,000 pounds; rubber, 20,000,000 pounds; stove polish, 4,000,000 to 5,000,000 pounds; all other uses, 1,000,000 pounds. Besides this in normal times probably 10,000,000 pounds are exported.

DISCUSSION OF IMPORTANT USES.

PRINTER'S INK.

Lampblack has been used as a pigment for printer's ink ever since the invention of the printing press, and until 1864 it was used almost exclusively. For printing requiring an extremely fine-grained ink great trouble was taken to purify the black. After the advent of carbon black in 1864, and its diminished cost after 1880, lampblack was less and less used in printer's ink; only a little is used at present time, and that only to impart certain qualities to an ink already containing carbon black.

According to Circular No. 53 of the United States Bureau of Standards—[27]

> The history of ink making shows that the development of the industry followed the improvement of inks, to gain the desired consistency, along the following lines: (1) The ink must have a certain body; (2) it must have a certain cohesion or flow (long or short); and (3) a certain adhesion or tack. An ink varnish is "long" when a drop falls away from a spatula with a long hairy string or thread; it is "short" when the drop is cut off sharply, with a very small tail.

Carbon black is peculiarly suited to the needs of present methods of printing, the fast-running presses and half-tone illustrations.

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[27] The composition, properties, and testing of printing inks, U. S. Bureau of Standards, Circ. 53, 1915.

Certain carbon blacks give a short ink; that is, an ink of buttery consistency which does not flow rapidly. This is especially desirable in lithographic and offset work, in slow-speed presses, and for most half-tones. Lampblack does not give the right consistency and is too gray. Certain other carbon blacks are used because for fast-running presses they make a fluid long ink which has opacity enough to give a black letter. Ink manufacturers and users believe that carbon black is absolutely essential to their business.

USE OF CARBON BLACK IN RUBBER.

Prior to 1914 carbon black was used by the rubber industry in small amounts for coloring. Little distinction was made between carbon black and lampblack, the two compounds being used indiscriminately. At the present time, partly on account of the stimulus afforded by the rising price of zinc oxide, carbon black is used in large amounts as a filler for rubber, with a correspondingly decreased amount of zinc oxide. Many rubber men claim unusual properties for rubber so compounded. Carbon black is used in rubber in quantities of 3 per cent to 20 per cent by weight, and is said to increase the tensile strength greatly and to give increased toughness and resistance to abrasion. Some authorities believe that the life of the rubber and its capacity to carry loads are increased. Other rubber chemists are more conservative and do not admit that carbon black possesses any properties that make it irreplaceable.

Carbon black is much cheaper than zinc oxide. In 1919 carbon black, specific gravity 1.8, suitable for compounding in rubber, could be procured for 9 cents a pound and zinc oxide, specific gravity of 5.8, cost at least as much. On a volume basis carbon black evidently cost one-third as much as an equal volume of zinc oxide. In practice, however, a greater volume of carbon black is used than of zinc oxide, therefore the resulting mix with carbon black contains less rubber per unit volume than the corresponding zinc-oxide mix.

Theoretically carbon black should be an ideal filler for rubber, owing to its extremely fine state of division and to the correspondingly large surface energy developed by mixing intimately with the gum rubber. It also serves to protect the rubber substance from the effects of light and it may retard oxidation. Whatever the exact facts may be as to the irreplaceability of carbon black in rubber, a large amount is now consumed by the rubber companies for automobile tires and other articles, probably 20,000,000 pounds annually besides 10,000,000 pounds exported in normal times. See also page 8.

USE OF CARBON BLACK IN PAINT.

Carbon black is coming into extensive use in paints. It has a higher tinting strength than any other black; a given weight will obscure a greater area of surface. Carbon black is acknowledged superior for varnishes and enamels. It is much used in making black and gray paints for general purposes. The United States War Department requires the use of carbon black in black enamels and in various black and gray paints. Some authorities [28] consider lampblack superior to carbon black and it is probably true that in certain gray tints lampblack is superior on account of its bluish-gray tones.

OTHER USES.

Other consumers of carbon black use the material because of its low cost and high coloring power. In phonograph records it produces a smooth surface for recording, although lampblack may also be employed. Carbon black makes a carbon paper that will produce opaque letters on a great many copies.

TESTING METHODS.

The suitability of a black for a given purpose is finally determined by actually trying out its working qualities. In making rubber a sample mix is prepared and the finished piece is tested for tensile strength, percentage of elongation, toughness, and resistance to abrasion. In ink manufacture a sample batch of ink is made up and the suitability of the black determined by an actual run on the press, the working qualities of the ink and the amount used for a given number of impressions being noted.[29]

A number of laboratory tests are useful in matching a standard sample. The tests most commonly employed are for tinting strength, color, and grit. It is also desirable to determine moisture, ash, and acetone extract.

PHYSICAL TESTS.

TINTING STRENGTH.

According to the American Society for Testing Materials, tinting strength is "the power of coloring a given quantity of paint or pigment selected as a medium or standard for estimating such power." Tinting strength, then, as applied to carbon blacks is the measure of the ability of the black to impart a color to a definite weight of standard white. It depends on the size of the particles and on the specific gravity of the black. In testing, the black is always compared with a standard black.

In making the test, weigh out accurately on a sensitive balance 0.100 gram of the black to be tested and 10.0 grams of a standard zinc white kept especially for the purpose. Transfer to a glass or marble slab and add from a burette exactly 3.5 c. c. refined linseed oil. Mix with a palette knife and rub out thoroughly with the palette knife, or better with a glass muller, until no streakiness or difference of color is observed when successive small portions are spread on a clean piece of window glass and viewed from the upper side. It is important that the rubbing out be thorough; 10 minutes is usually time enough for it. Follow the same procedure with the standard black. Then spread a small amount of each mix side by side on a clean glass, as a microscope object glass. Examination of the samples from the other side of the glass, particularly at the line where they overlap, will show the difference in tinting strength.

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[28] Maire, Frederick, Modern pigments and their vehicles, 1908, p. 226. Toch, Maximilian, The chemistry and technology of paints, 1916, p. 366.

[29] For a detailed discussion of printing inks, *see* The chemistry and technology of printing inks, Norman Underwood and John V. Sullivan, 1915; The composition, properties, and testing of printing inks, U. S. Bureau of Standards, Circ. 53, 1915.

To make a quantitative estimation of the tinting strength of the sample as compared to the standard, more white is added to the stronger mix until the colors match. A new sample of the stronger black is then weighed out, using the calculated amount of zinc white, and the process is repeated until mixes of the same color are obtained. If, for example, it was necessary to mix 15 grams of zinc white with 0.1 gram of the standard to match a mixture of 10 grams zinc white and 0.1 gram of the sample, then the sample has 66⅔ per cent the strength of the standard.

COLOR.

By the term color is meant the relative blackness of the material when mixed in oil. In making the color test, take 0.3 gram of each of the blacks to be compared and add 1.3 c. c. of refined linseed oil from a burette. Mix thoroughly with the palette knife, spread side by side on a slip of glass, and compare the relative color by viewing from the upper side of the glass.

GRIT.

Presence of gritty matter is determined by rubbing a portion of the black under the finger or by placing a small amount on the tongue and rubbing it between the tongue and palate.

HIDING POWER.

In tests of paint pigments *hiding power* and *spreading rate* are often determined. Carbon blacks made by the present process as a rule vary so little among themselves in these two properties that testing by the present methods is probably of little value. A brief description of the two terms may, however, be of interest.

Hiding power is the ability of a pigment when mixed in oil to obscure a surface on which it is painted. In making the tests, equal weights of each pigment and equal quantities of oil are mixed together. The mixes are then spread on a prepared board marked off in black and white squares so that the squares are just obliterated.

The brush is weighed before and after painting. The smaller the weight used for a given area, the greater the hiding power of the paint

Dr. A. H. Pfund, of Johns Hopkins University, has designed an instrument, the cryptometer, for determining the hiding power of white pigments and paints that might be modified for use with carbon blacks. Briefly the principle of the instrument is as follows:

> Granting that an infinitely thick layer of paint will "hide" a given background completely, it is desired to find the least thickness of layer which will hide the background as effectively as does the infinitely thick layer. This purpose is accomplished by means of the cryptometer, which yields numerical values of the hiding power of the pigment in terms of the number of square centimeters which 1 gram of the pigment will cover and hide, as well as of the hiding power of a paint, expressed in square feet per gallon.[30]

SPREADING RATE.

The spreading rate of a paint is the ability of the paint to coat a surface. The American Society for Testing Materials thus illustrates the term:

> The paint when spread on a planished iron surface at the rate of 600 square feet to the gallon will not sag or run when placed in a vertical position at 70° F.

The test is performed in a manner similar to the testing of hiding power.

CHEMICAL TESTS.

It is occasionally desirable to make a few quantitative chemical tests of carbon black. A black containing more than 0.2 per cent ash is probably adulterated with mineral black or charcoal. An acetone extract over 0.1 per cent indicates adulteration with a poorly calcined lampblack. Too great a percentage of moisture is undesirable. Certain blacks will absorb as much as 15 per cent of their weight of moisture, making a total moisture content of 20 per cent or more. Most blacks for making ink contain from 2 to 4 per cent of moisture, although certain blacks may contain as high as 7 per cent.

MOISTURE.[31]

A 1-gram sample of the black is placed in a weighed porcelain crucible and heated for one hour at 105° C. in a constant temperature oven in circulating dry air. The crucible is then removed from the oven, covered, and cooled in a desiccator over sulphuric acid. The loss in weight multiplied by 100 is recorded as the percentage of moisture.

ASH.[31]

The crucible containing the residue from the moisture determination is heated gradually with a Meker burner, or better in a muffle furnace, to about 750° C. or to a cherry red. Ignition is continued until all the particles of carbon have disappeared. The crucible is then cooled in a desiccator and weighed, after which it is heated again for 15 minutes, cooled, in a desiccator, and reweighed. If the change in weight is more than 0.0002 gram, the process is repeated until successive weighings are constant to this figure. The weight of the crucible and ash minus the weight of the crucible is taken as the weight of the ash.

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[30] A. H. Pfund, personal communication.

[31] For details of method see Tech. Paper 8, Bureau of Mines, "Methods for analyzing coal and coke," by F. M. Stanton and A. C. Fieldner.

ACETONE EXTRACT.

A 2-gram sample is weighed into an alundum or paper extraction thimble of 20 c. c. capacity and the extraction carried out for one hour, using any standard apparatus of the Soxlet type. The weight of the residue after evaporation of the acetone is taken as the acetone extract. The extract for a pure carbon black is usually zero.

Carbon blacks vary in color and tinting strength. As a rule, the less volatile matter a carbon black contains, the blacker is its color. Tinting strength of carbon blacks high in volatile matter is usually higher than that of the carbon blacks which are purer carbon. This may be due to the fact that blacks containing more volatile matter are more dispersed and hence more effectively hide the zinc-white particles.

SPECIFICATIONS.

The bureau has received a great many inquiries in regard to tests that a carbon black must meet to be suitable for use in printing ink or rubber. The following specifications represent an attempt to gather the requirements adopted by the trade. No hard and fast specifications for carbon black exist and the test on which a black stands or falls is the practical test:

PRINTING INK.

CHEMICAL TESTS.		PHYSICAL TESTS.	
Moisture	less than 5.0 per cent.	Color	must match standard.
Ash	less than 0.1 per cent.	Tinting strength	must equal standard.
Acetone extract	less than 0.1 per cent.	Grit	none.

PRACTICAL TESTS.

The black when made into ink must have satisfactory working qualities as determined by an actual run on the press for which the ink is intended. The ink must have satisfactory transfer, tack, drying properties, color, and must print a sufficient number of pages per pound. The oil must not separate from the pigment and there must be no offset or smutting.

TESTING METHODS.

Chemical and physical tests are performed as previously described. Practical tests are to be made on the press for which the ink is intended. Specifications for tests of halftone black ink, taken from the set of requirements and tests formulated by the Government Printing Office, are given below. A slightly different set of requirements must be satisfied for other kinds of ink.[32] The requirements for a satisfactory test are as follows for halftone black ink:

1. *Nonseparation of oil from pigment.*—The oil or varnish should not separate from the pigment either on the face of the type or cuts, or in the fountain, but should be short enough to break up readily in the distribution and not "string."
2. *Transfer.*—In transferring from type or cuts to paper the ink should leave the face of the type or cuts reasonably clean.
3. *Hardness.*—Ink should dry hard on the paper in eight hours to admit of easy handling without damage or injury to the work, and should not pull the coating or the face from the paper, nor the face from the roller.
4. *Drying.*—Ink should not dry on the form, rollers, or distribution so that it may not be easily removed therefrom.
5. *Offset or smutting.*—The ink must be able to carry sufficient color to print clean and sharp, without offset or smut on sheets falling on top from the press fly or in piling the work.
6. *Color.*—The ink must dry a deep, solid carbon (not aniline) black, and not turn gray nor have a metallic sheen or luster, nor blister the face of the paper.
7. *Quantity required.*—The weight of the amount used must be noted and averaged on a basis of 5,000 printed pages.

METHODS TO BE USED IN MAKING THE PRACTICAL TESTS.

1. The practical test of halftone black ink shall be made on the flat-bed presses in use in the Government Printing Office.
2. The test shall be made on coated book paper of the size, weight, and quality in general use in the Government Printing Office.
3. The type or cut forms shall be previously "made ready" and the press otherwise in good condition to make a satisfactory run.
4. The form, rollers, distribution, and ink fountain shall then be thoroughly washed and cleaned. The ink to be tested shall be weighed before being placed in the fountain. The quantity to be tested should be sufficient to run not less than three hours, and preferably a run of five hours should be made.

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[32] See Report on ink test, Form S-888, Government Printing Office, Press Division, or The composition, properties, and testing of printing inks, Bureau of Standards, Circ. 53, 1915.

5. Ink that will separate the oil or varnish from the pigment on the face of the form or in the fountain will not be accepted.

6. To be satisfactory ink under the impression should transfer from the face of the type or cuts to the paper, leaving the face of the type or cuts reasonably clean. It should be heavy in body, should feed well, and have sufficient "tack" to dry on the paper rapidly enough while printing to avoid the necessity of using slip sheets; but it should dry hard on the paper in eight hours, so that the work can be handled easily without damage or injury to the printing. It must not pull the face or coating from the paper and leave it on the face or form, or pull the face from the rollers. It should be removed easily from the form, rollers, and distribution, must be able to carry sufficient color without offset or smut, and print clean and sharp.

7. The ink to be satisfactory must dry a deep, solid carbon (not aniline) black, and not turn gray, nor have a metallic sheen or luster, nor blister the face of the paper.

After the test has been made, the remaining quantity of the ink shall be removed from the fountain and weighed, a reasonable allowance being made for the ink necessarily left in the fountain, on the rollers, and distribution, in order to determine the number of copies a given quantity of ink will print.

RUBBER.

CHEMICAL TESTS.		PHYSICAL TESTS.	
Moisture	Less than 4 per cent.[33]	Grit	None (should completely pass through a 100-mesh sieve and feel as an impalpable powder when rubbed under the finger).
Acetone extract	Less than ½ per cent.	Tinting strength	Not less than 90 per cent the strength of standard.
Ash	Less than 0.25 per cent.		

PRACTICAL TESTS.

Rubber mixes are made up containing equal weight of the sample to be tested and of the standard. Mixes are cured under exactly the same condition. The finished sheet is tested for tensile strength, per cent elongation, toughness, and resistance to abrasion.

PAINT.

CHEMICAL TESTS.		PHYSICAL TESTS.	
Moisture	Less than 5 per cent.	Tinting strength	Not less than 95 per cent the strength of standard.
Ash	Less than 1.25 per cent.		

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[33] Some rubber chemists place this figure as low as 2½ per cent.

PRELIMINARY WORK ON OTHER LABORATORY TESTS.

Some attention has been given to the possibility of devising tests that will predict in a quantitative way the performance of the black when made into ink, and preliminary work has been done on the problem.

Tests that suggest themselves are: Measurements of (1) viscosity, (2) cohesion, and (3) adhesion of mixtures of black and oil. Determination of these three properties should throw light on the probable performance of the black in use.

VISCOSITY.

Attempts to measure the viscosity of mixtures of black and linseed oil in a Saybolt viscosimeter were unsatisfactory because an extremely dilute mixture was necessary. Accordingly it was decided to try out the MacMichael torsion viscosimeter,[34] which is used in the petroleum laboratory at the Pittsburgh station for determining the viscosity of heavy oils. In this instrument a brass disk connected to a graduated torsion head is suspended from a piano wire in a rotating cup containing the liquid to be tested. Deflection is proportional to viscosity at any given rate of revolution. By use of a suitable wire, liquids of very high viscosity can be tested. The apparatus is calibrated with a liquid of known viscosity. Mixtures of equal weights of various blacks with the same amount of raw linseed oil were made up and the viscosity determined by means of the MacMichael apparatus. It was found that carbon blacks prized by ink makers on account of their "length" gave a lower reading on the viscosimeter than other blacks.

At this time the author's attention was drawn to a paper by Bingham[35] on measurements of the mobility and "yield value" of paint. Bingham distinguishes between the viscosity of true liquids and the rigidity of plastic solids. Measurements of the flow through a capillary when different pressures are applied to the liquid show that the curve of pressure against the volume flowing through in unit time is different for true liquids and for plastic solids. In a true liquid the curve passes through the origin; for a plastic solid, the curve cuts the pressure axis at some distance on one side of the origin. This distance Bingham calls the yield value or force that must be applied to the plastic solid before any deformation takes place. It appeared possible to obtain similar curves using the torsion viscosimeter by measuring the deflection at different speeds of rotation, the speed of rotation corresponding to the volume flowing through the capillary, and the deflection corresponding to the pressure. Mixes of several blacks were made up, using 10 grams of black to 100 c. c. of raw linseed oil. These were run at different speeds in the torsion viscosimeter at a temperature of 80° F. Curves are shown in figure 17.

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[34] MacMichael, R. F., A new direct reading viscosimeter: Jour. Ind. Eng. Chem., vol. 7, 1915, pp. 961–3. Bureau of Mines Reports of Investigation No. 2201.

[35] Bingham, E. C., and Green, Henry. Paint, a plastic material and not a viscous liquid: Preprint Am. Soc. Test. Mat., 22d Ann. Meeting, June 24 to 27, 1919.

It will be noticed that at the higher speeds the points lie on a straight line and the extrapolation of this line back to zero revolutions per minute does not pass through zero deflection. These curves are similar to those obtained by Bingham with the capillary method. It is possible to obtain a relative figure for the rigidity or mobility and the yield value from these data. Relative rigidity is obtained from the following relationship:

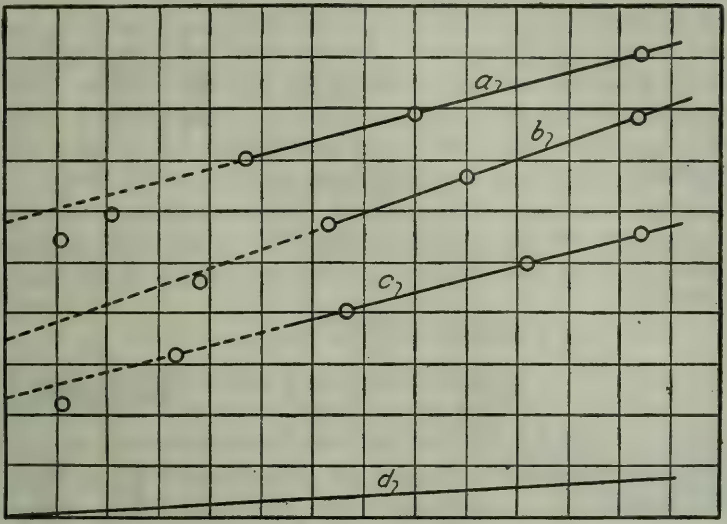

Figure 17.—Curve showing the viscosity of mixture of carbon black and linseed oil: *a*, Short carbon black; *b*, lampblack; *c*, long carbon black; *d*, linseed oil.

$$R_{rel} = t\,(d_t - d_{t\infty})$$

Where t is the time of one revolution in seconds, d_t the deflection, and $d_{t\infty}$ the deflection at zero revolutions per minute. Data and calculated relative rigidity and mobility are given in the following table:

Table 13.—*Viscosity of mixtures of carbon black and lampblack with linseed oil.*

SHORT CARBON BLACK.

Revolutions per minute.	Deflection.	Time of 1 revolution, seconds.	Relative rigidity.	Relative mobility.
124	90	0.48	15.4	0.0650
80	79	.75	15.7	.0637
47	70	1.28	15.4	.0650
21	59	2.86		
11	54	5.45		

Yield value = 58.

TABLE 13.—*Viscosity of mixtures of carbon black and lampblack with linseed oil*—Con.

LAMPBLACK.

Revolutions per minute.	Deflection.	Time of 1 revolution, seconds.	Relative rigidity.	Relative mobility.
124	78	0.48	20.6	0.0486
90	66	.67	20.8	.0481
63	57	.95	20.9	.0478
38	46	1.58	17.4	.0575

Yield value=35.

LONG CARBON BLACK.

Revolutions per minute.	Deflection.	Time of 1 revolution, seconds.	Relative rigidity.	Relative mobility.
124	55	0.48	15.4	0.0650
102	49	.59	15.3	.0654
67	40	.90	15.2	.0658
33	31	1.82	14.6	.0685
11	22	5.45	....	....

Yield value=23.

RAW LINSEED OIL.

Revolutions per minute.	Deflection.	Time of 1 revolution, seconds.	Relative rigidity.	Relative mobility.
124	7	0.48	3.4	0.0194
70	4	.86	3.4	.0194

Yield value=0.

SUMMARY.

	Relative rigidity.	Relative mobility.	Yield value degrees deflection.
Short carbon black plus linseed oil	15.0	0.067	59
Long carbon black plus linseed oil	15.3	.065	23
Lampblack plus linseed oil	22.0	.046	33
Raw linseed oil alone	3.4	.019	0

DISCUSSION OF RESULTS.

It is at once seen that the difference between the long and short blacks tested is a difference principally in yield value, and that the mobilities of the two mixtures are nearly the same. This relation is also seen at once by inspection of the curves that show the same slope for the two blacks. The lampblack with a steeper slope has a lower mobility and a yield value intermediate between the long and short blacks.

The yield value is apparently the resistance, probably because of attractive forces between the particles of black, that the mixture offers to deformation when the load is applied above a certain rate. If the load is applied slowly, a different condition obtains as shown by the falling off of the curve from a straight line at the lower speeds of revolution. If the rotation of the cup is stopped while a mixture is being tested, the deflection drops back quickly to a point near the yield value and then slowly decreases nearly to zero over a period of several minutes. It is hoped to continue work with the torsion viscosimeter and to compare results as obtained with it to the results obtained by the capillary method. Results are of course empirical, but might nevertheless be of practical value.

COHESION.

Cohesion is defined as the attraction between the particles of the same substance. It is the resistance a substance offers to deformation. An ink with low cohesion is a long ink, that is, it allows itself to be changed in shape and easily drawn out into strings. One with higher cohesion offers greater resistance to deformation and breaks off when an attempt is made to draw it out into a string with the palette knife. Cohesion may be measured by determining the force necessary to draw a flat circular plate away from the surface of the liquid on which it is resting. In order to get duplicable results with a mixture such as ink, the force must be applied quickly. If the force is applied slowly, the same indefinite results are obtained as in the viscosity determinations at the lower speeds, probably owing to slippage. Results of a few measurements of this character with long and short black mixtures show long blacks to have lower cohesion.

ADHESION.

The molecular attraction between the surface of bodies in contact is called adhesion. When a liquid wets a solid the adhesion between the liquid and solid is more powerful than the cohesion of the liquid, as is shown in the method of determining the force of cohesion. When the plate is pulled from the liquid, the plate is wet with the liquid showing that the cohesion of the liquid has been overcome but its adhesion for the plate has not been overcome. The adhesion of an ink for the type and paper must influence its working qualities, and constitutes what the printer calls "tack". Adhesion of a liquid may be measured by dipping a weighed metal plate in the liquid, allowing it to drain at a constant temperature, and reweighing. For a plastic material, such as ink or paint, the value for the adhesion so obtained would probably be modified by the yield value of the mixture.

In making any tests of mixtures of carbon or lampblack in oil, care must be taken that the black is thoroughly incorporated with the oil if duplicable results are to be obtained. The mixture should be thoroughly ground in a paint mill or in a three-roller ink mill. An inert mineral oil would probably be better than linseed oil for testing purposes.

COMPLETE CHEMICAL ANALYSES OF CARBON BLACKS.

In the course of the work, complete proximate and ultimate analyses and determination of true density of a number of different carbon blacks on the market have been made. Analyses were made under the direction of W. A. Selvig, analytical chemist. The standard procedure used at the Bureau of Mines for coal analyses was followed.[36]

Analyses of lampblacks and several other blacks were made for the sake of comparison and the results are set down in the following tables:

TABLE 14.—*Analyses of carbon black.*

	Long black No. 1.	Long black No. 2.	Long black No. 3.	Short black No. 1.	Short black No. 2.	Short black No. 3.
PROXIMATE ANALYSIS.						
Moisture	3.56	7.13	5.30	2.25	3.02	3.12
Volatile matter	11.99	13.41	10.40	5.60	5.48	5.58
Fixed carbon	84.40	79.44	84.16	92.13	91.47	91.22
Ash	.05	.02	.14	.02	.03	.08
ULTIMATE ANALYSIS (AS RECEIVED).						
Hydrogen	1.19	1.32	1.11	.74	.88	1.05
Carbon	88.17	84.56	87.98	94.78	93.50	93.63
Nitrogen	.04	.04	.08	.09	.04	.05
Oxygen	10.54	14.00	10.68	4.37	5.25	5.19
Sulphur	.01	.06	.01	.00	.30	.00
Ash	.05	.02	.14	.02	.03	.08
ULTIMATE ANALYSIS (MOISTURE FREE).						
Hydrogen	.82	.57	.55	.50	.52	.72
Carbon	91.42	91.05	92.91	96.96	96.41	96.64
Nitrogen	.04	.04	.08	.09	.04	.05
Oxygen	7.66	8.26	6.30	2.43	2.69	2.51
Sulphur	.01	.06	.01	.00	.31	.00
Ash	.05	.02	.15	.02	.03	.08
True specific gravity	1.80	1.78	1.88	1.85	1.80	1.78

TABLE 15.—*Lampblacks and other blacks.*

	Lampblack.		Bone black.	Vine black.	Willow charcoal.	Wood pulp black.	Carbon from cracking of methane.	
	No. 1.	No. 2.					No. 1.	No. 2.
PROXIMATE ANALYSIS.								
Moisture	0.39	3.12	3.88	9.58	3.24	6.42	0.02	1.25
Volatile matter	2.26	17.38	10.92	29.54	14.66	9.78	.78	6.40
Fixed carbon	97.35	79.44	2.68	40.50	80.23	78.84	98.36	92.11
Ash	.00	.06	82.52	20.38	1.87	4.96	.84	.24
ULTIMATE ANALYSIS (AS RECEIVED).								
Hydrogen	.52	1.51	.88	2.44	2.74	1.60	.45	1.26
Carbon	97.62	87.84	8.64	51.65	85.04	83.20	98.70	96.76
Nitrogen	.11	.00	1.06	.80	.16	.17	.01	.01
Oxygen	1.18	9.95	6.84	24.41	10.11	9.59	....	1.61
Sulphur	.57	.64	.06	.32	.08	.48	.05	.12
Ash	.00	.06	82.52	20.38	1.87	4.96	.84	.24
ULTIMATE ANALYSIS (MOISTURE FREE).								
Hydrogen	.48	1.20	.47	1.53	2.46	.95	.45	1.13
Carbon	98.00	90.67	8.99	57.12	87.89	88.91	98.72	97.99
Nitrogen	.11	.00	1.10	.88	.17	.18	.01	.01
Oxygen	.84	7.41	3.53	17.58	7.47	4.15	....	.51
Sulphur	.57	.66	.06	.35	.08	.51	.05	.12
Ash	.00	.06	85.85	22.54	1.93	5.30	.02	.24
Acetone extract	.165	6.50	....	....	....	....	.02	.16

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[35] Stanton, F. M., and Fieldner, A. C., Methods of analyzing coal and coke: Tech. Paper 8, Bureau of Mines, 1913. Fieldner, A. C., Notes on the sampling and analysis of coal: Tech. Paper 76, Bureau of Mines, 1914.

TABLE 16.—*Complete record of analyses of carbon blacks, lampblacks, and other blacks.*

Brand.	Manufacturer.	Method of manufacture.	Laboratory No.	Condition.a	Proximate.				Ultimate.					Calorific value.		Real specific gravity.
					Moisture.	Volatile matter.	Fixed carbon.	Ash.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Sulphur.	Calories.	B. t. u.	
G Elf carbon black.	G. L. Cabot	24-foot plates, large burners, Grantsville, W. Va.	31522	1	2.76	10.49	86.64	0.11	1.02	91.97	0.02	6.86	0.02	7,578	13,640	....
				2	......	10.79	89.10	.11	.73	94.58	.02	4.54	.02	7,793	14,027	....
P N Elf carbon black.	do	3-foot plates, large burners, Spencer, W. Va.	32384	1	2.58	8.37	89.04	.01	1.14	92.20	.07	6.17	.41	7,592	13,666	....
				2	......	8.59	91.40	.01	.87	94.64	.07	3.99	.42	7,793	14,027	1.74
New Vulcan carbon black.	do	3-foot plates, average size lava tips, Grantsville, W. Va.	32380	1	3.12	5.58	91.22	.08	1.05	93.63	.05	5.19	.00	7,651	13,772	....
				2	......	5.76	94.16	.08	.72	96.64	.05	2.51	.00	7,897	14,215	1.78
Monarch carbon black.	do	Channels, medium size lava tips, Glasgow, W. Va.	32379	1	2.34	6.16	91.50	.00	.78	92.90	.08	6.22	.02	7,596	13,673	....
				2	......	6.31	93.69	.00	.53	95.13	.08	4.24	.02	7,778	14,000	1.86
Kalista carbon black	do	Cylindrical rollers, cylindrical burners, Creston, W. Va.	32381	1	5.30	10.40	84.16	.14	1.11	87.98	.08	10.68	.01	7,106	12,791	....
				2	......	10.98	88.87	.15	.55	92.91	.08	6.30	.01	7,504	13,507	1.88
Auk carbon black	do	Channels, medium size lava tips, Glasgow, W. Va.	32383	1	2.64	7.06	90.30	.00	.86	92.53	.06	6.55	.00	7,570	13,626	....
				2	......	7.25	92.75	.00	.59	95.04	.06	4.31	.00	7,775	13,995	1.85
Long carbon black.	Binney & Smith	Probably cylindrical roller system.	32266	1	7.13	13.41	79.44	.02	1.32	84.56	.04	14.00	.06	6,817	12,271	....
				2	......	14.44	85.54	.02	.57	91.05	.04	8.26	.06	7,341	13,214	1.78
Short carbon black.	do	Probably channel or 3-foot disk.	32265	1	3.02	5.48	91.47	.03	.88	93.50	.04	5.25	.30	7,618	13,712	....
				2	......	5.65	94.32	.03	.52	96.41	.04	2.69	.31	7,855	14,139	1.80
Rubber carbon black.	do	do	32267	1	3.02	5.33	91.62	.03	1.02	93.82	.02	5.06	.05	7,778	14,000	....
				2	......	5.50	94.47	.03	.70	96.74	.02	2.46	.05	8,020	14,436	1.81
No. 54 carbon black.	do	Unknown	31984	1	2.48	8.07	89.43	.02	.99	92.74	.03	6.20	.02	7,660	13,788	....
				2	......	8.27	91.71	.02	.73	95.10	.03	4.10	.02	7,855	14,139	1.82
Sample from a rubber company carbon black.			31985	1	2.74	7.81	89.42	.03	.78	92.86	.03	6.29	.01	7,635	13,743	....
				2	......	8.03	91.94	.03	.49	95.48	.03	3.96	.01	7,850	14,130	....
Triangle carbon black.	Eastern Carbon Co.	3-foot disks, Shrewsbury and Barren Creek, W. Va.	32006	1	2.25	5.60	92.13	.02	.74	94.78	.09	4.37	.00	7,706	13,871	....
				2	......	5.73	94.25	.02	.50	96.96	.09	2.43	.00	7,883	14,189	1.87
Bull's-eye carbon black.	do	Unknown	32007	1	3.56	11.99	84.40	.05	1.19	88.17	.04	10.54	.01	7,212	12,982	....
				2	......	12.43	87.52	.05	.82	91.42	.04	7.66	.01	7,478	13,460	1.80
Germantown lampblack.	Patton Co	Incomplete combustion of oil, probably "dead oil."	32547	1	.39	2.26	97.35	.00	.52	97.62	.11	1.18	.57	7,986	14,375	....
				2	......	2.27	97.73	.00	.48	98.00	.11	.84	.57	8,017	14,431	1.70
Lampblack	Binney & Smith	do	31983	1	3.12	17.38	79.44	.06	1.51	87.84	.00	9.95	.64	7,386	13,295	....
				2	......	17.94	82.00	.06	1.20	90.67	.00	7.41	.66	7,624	13,723	....
Do	L. Martin Co	do	32548	1	2.47	14.66	82.77	.10	1.76	88.94	.10	8.34	.76	7,484	13,471	....
				2	......	15.03	84.87	.10	1.53	91.19	.10	6.30	.78	7,673	13,811	....
Black from cracking natural gas.		Heated retort, Carbo-Hydrogen Co., Coraopolis, Pa.	32545	1	.02	.78	98.36	.84	.45	98.70	.01	......	.05	7,948	14,306	....
				2	......	.78	98.38	.84	.45	98.72	.01	......	.05	7,950	14,310	1.72
Do		By turning pure gas into a hot surface combustion furnace.	32546	1	1.25	6.40	92.11	.24	1.26	96.76	.01	1.61	.12	8,102	14,584	....
				2	......	6.48	93.28	.24	1.13	97.99	.01	.51	.12	8,205	14,769	....

a The form of analysis is denoted by number as follows: 1=sample as received; 2=dried at a temperature of 105° C.; 3=moisture and ash free.

TABLE 16.—*Complete record of analyses of carbon blacks, lampblacks, and other blacks*—Continued.

Brand.	Manufacturer.	Method of manufacture.	Laboratory No.	Condition.	Proximate.				Ultimate.					Calorific value.		Real specific gravity.
					Moisture.	Volatile matter.	Fixed carbon.	Ash.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Sulphur.	Calories.	B. t. u.	
Bone black........	Binney & Smith..	....	31986	1	3.88	10.92	2.68	82.52	0.88	8.64	1.06	6.84	0.06	668	1,202	....
				2	......	11,36	2.79	85.85	.47	8.99	1.10	3.53	.06	695	1,251	....
				3	......	80.28	19.72	....	3.32	63.53	7.77	24.96	.42	4,912	8,842	....
Vine black........	.....do..........	....	31987	1	9.58	29.54	40.50	20.38	2.44	51.65	.80	24.41	.32	4,079	7,342	....
				2	......	32.67	44.79	22.54	1.53	57.12	.88	17.58	.35	4,511	8,120	2.02
				3	......	42.18	57.82	....	1.98	73.74	1.14	22.69	.45	5,824	10,483	....
Willow charcoal....	.....do..........	....	31958	1	3.24	14.66	80.23	1.87	2.74	85.04	.16	10.11	.08	7,514	13,525	....
				2	......	15.15	82.92	1.93	2.46	87.89	.17	7.47	.08	7,766	13,979	....
				3	......	15.45	84.55	....	2.51	89.62	.17	7.62	.08	7,919	14,254	....
Wood-pulp black..	.....do..........	....	31989	1	6.42	9.78	78.84	4.96	1.60	83.20	.17	9.59	.48	6,973	12,551	....
				2	......	10.45	84.25	5.30	.95	88.91	.18	4.15	.51	7,451	13,412	....
				3	......	11.04	88.96	....	1.00	93.89	.19	4.38	.54	7,868	14,162	....

DISCUSSION OF ANALYSES.

Analyses show that carbon blacks are by no means pure carbon; some of them contain as low as 91 per cent carbon on a moisture-free basis. It will be noted that the blacks classified as long blacks are higher in volatile matter, oxygen, and moisture than the short blacks. True specific gravity varies from 1.78 to 1.88. This determination is made on the moisture-free sample. Apparent specific gravity varies from 0.15 to 0.20, depending partly on the amount of pressure put on the black in packing. If the blacks are placed in a tube and centrifuged at a high rate of speed, the apparent specific gravity is increased to 0.25.

Carbon made by cracking methane in a heated retort, if made at a very high temperature, is usually nearly pure carbon. See No. 1 in Table 15. When made at a lower temperature, considerable amounts of polymerization products, as naphthalene, may be present in the material. See No. 2 in Table 15. Unless well calcined, lampblack usually contains considerable empyreumatic matter that shows up in the analysis as a high figure for volatile matter and acetone extract. See lampblack No. 2 in Table 15; lampblack No. 1 is a calcined material. The true density of the lampblacks analyzed was about 1.70, a figure that is probably low on account of the difficulty of wetting the material with water. For an accurate determination of the true density of lampblacks, another liquid should be used, such as benzol. The apparent density of the lampblacks was about 0.09. The true specific gravity of the other blacks varies from 1.7 for wood-pulp black to 2.02 for vine black. Apparent specific gravity for wood-pulp black is 0.28 and for vine black 0.75.

ADSORBED GASES.

Carbon black contains considerable quantities of carbon monoxide, carbon dioxide, and oxygen. The oxygen is probably present as "fixed oxygen," that is, in some kind of combination with the carbon. Through the cooperation of Dr. G. A. Hulett and H. E. Cude, of Princeton University, the nature and amount of the adsorbed gases were determined. The apparatus used was that designed by Dr. Hulett to determine the nature of the adsorbed gases in gas-mask charcoal. The gases are pumped off at any desired temperature by means of a Topler pump and are analyzed, the water being caught on a bulb containing solid carbon dioxide.

The composition of the gases which can be pumped off at room temperature is practically that of air, and the volume approximately that of the voids and capillary spaces. At 445° C. a larger volume usually comes off, consisting chiefly of CO_2, CO. Carbon dioxide may be present in as large an amount as 1 per cent of the weight of the moisture and the gas-free black, oxygen about 0.01 per cent, CO, 0.1 to 0.2 per cent, methane and hydrogen, a trace, nitrogen 0.05 to 0.2 per cent. An insufficient number of samples was analyzed to allow conclusions to be drawn in regard to the relation between the adsorbed gases and the physical and chemical properties. At the temperatures investigated, none of the hydrogen indicated by the ultimate analysis was pumped off. The carbon dioxide evolved would account only for part of the oxygen shown by the ultimate analysis to be present. (See tables 17, 18, and 19.)

TABLE 17.—*Adsorbed gases in carbon black.*

[True density of blacks and volume of adsorbed gases.]

Labratory No.	Material.	Weight, gas and moisture free.	Water, per cent original material.	Density, grams, per c. c.	Volume of gas pumped off.[a]	
					Room temperature, c. c.	445° C. c. c.
32006	Short black No. 1	3.2841	3.15	1.871	15.40	23.02
32265	Short black No. 2	2.4206	3.88	1.872	15.25	9.95
32007	Long black No. 1	3.1805	6.84	1.893	13.55	25.80
32266	Long black No. 2	2.8370	9.49	1.952	16.75	19.45

[a] Corrected to 0° C. and 760 mm.

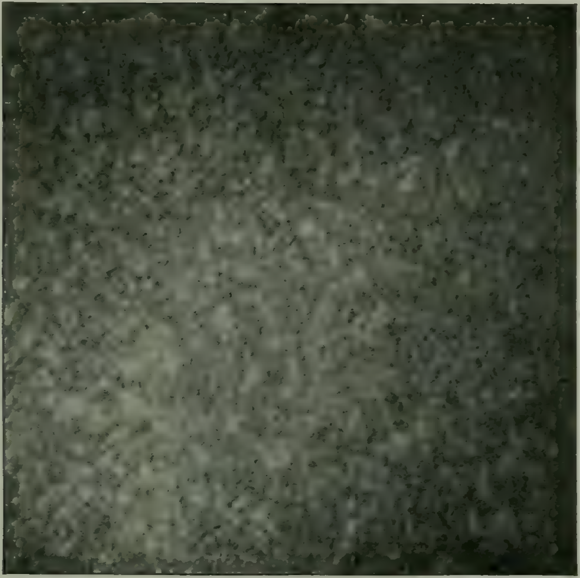
TABLE 18.—*Analysis of gas pumped off at room temperature.*

Volume.	Short black No. 1, 15.40 c. c.	Short black No. 2, 15.25 c. c.	Long black No. 1, 13.55 c. c.	Long black No. 2, 16.75 c. c.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
CO_2	0.7	1.4	1.3	0.8
O_2	20.2	19.1	18.6	22.1
CO	0	.2	.1	.2
CH_4	.2	.1	.2	.0
H_2	.0	.0	.0	.0
N_2	78.9	79.2	79.8	76.9
Total	100.0	100.0	100.0	100.0

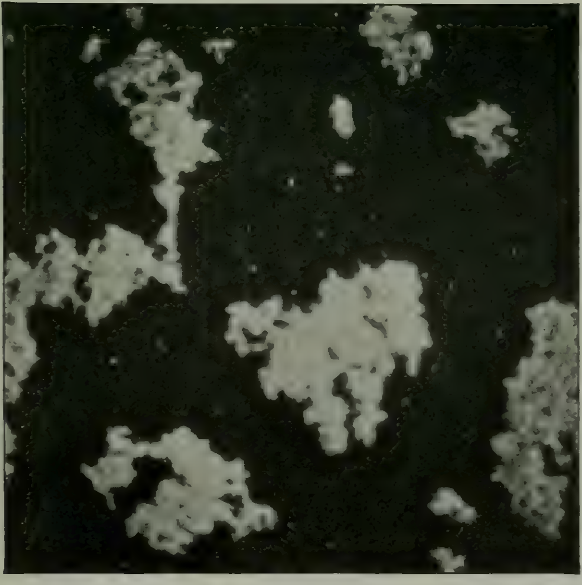
TABLE 19.—*Analysis of gas pumped off at 445° C.*

Volume.	Short black No. 1, 23.02 c. c.	Short black No. 2, 9.95 c. c.	Long black No. 1, 25.80 c. c.	Long black No. 2, 19.45 c. c.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
CO_2	67.2	51.9	64.19	73.5
O_2	.9	2.7	.62	1.2
CO	26.2	30.0	12.22	15.9
CH_4	.0	1.2	.41	.5
H_2	.0	0.5	.07	.2
N_2	5.7	13.7	22.49	8.7
Per cent of black by weight.[a]				
CO_2	.924	.418	1.020	.990
O_2	.009	.016	.007	.010
CO	.230	.154	.124	.140
CH_4	.000	.004	.002	.002
H_2	.000	[b].000	.000	[c].000
N_2	.050	.070	.228	.074

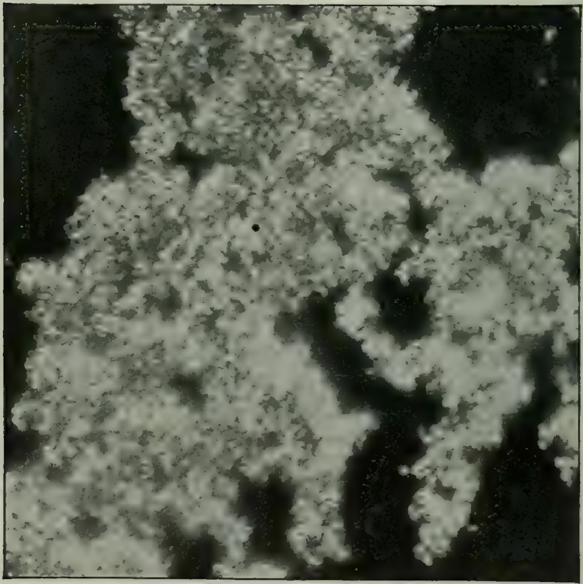
[a] Gas and moisture free. [b] Probably .0002. [c] Probably .0001.



A. SHORT BLACK 18 MINUTES AFTER PREPARATION ON SLIDE. MAGNIFIED 500 DIAMETERS.



B. SHORT BLACK TWO HOURS AFTER PREPARATION ON SLIDE. MAGNIFIED 500 DIAMETERS.



SHORT BLACK TWO HOURS AFTER PREPARATION ON SLIDE. MAGNIFIED 2,000 DIAMETERS.

HYGROSCOPICITY.

Carbon blacks absorb moisture when exposed to damp air and too large a moisture content is detrimental to the working qualities of the black in ink. Blacks containing a high percentage of volatile matter, as long blacks, are as a rule more hygroscopic than are those containing a lesser amount of volatile matter. Inasmuch as any considerable percentage of moisure is detrimental to the working qualities of the black, it is important that original packages of carbon black be kept unbroken in a dry room until ready for use. The following table shows results of exposing weighed amounts of different blacks over water and over sulphuric acid at a temperature of about 25° C. The blacks when initially weighed were in equilibrium with a humidity of about 60 per cent at 25° C.

TABLE 20.—*Hygroscopicity of carbon black.*

	Per cent loss in weight over H_2SO_4.		Per cent gain in weight over H_2O.		Moisture at 105° C.
	24 hours.	72 hours.	24 hours.	72 hours.	
Long black No. 1	3.9	4.2	4.9	10.3	3.6
Long black No. 2	6.2	6.9	7.0	14.1	7.1
Short black No. 1	2.4	2.6	3.1	6.7	2.3
Short black No. 2	2.2	2.5	3.6	7.7	3.0

MICROSCOPIC EXAMINATION.

The photomicrographs of carbon black were taken by Dr. Reinhardt Thiessen, of the Pittsburgh station, and the following discussion of the bearing of the photomicrographs on the properties exhibited by carbon black in ink was written in collaboration with Dr. Thiessen.

According to the ink manufacturers, various grades of carbon black show very different properties when made into ink. Underwood [37] says:

> There is a wide range in the behavior of different carbon blacks, a wider range than there is any apparent cause for. They vary from making short tacky inks to making inks of great natural length and decided flow, while some carbon blacks which we have had experience with were absolutely useless for making any kind of ink, even news ink.

The terms "length" and "shortness" are explained by Underwood as follows:

> If a pigment when mixed with a large quantity of oil still remains stiff or can not be drawn out into a string between the fingers but breaks, it is said to be short. While there are some classes of work that require ink of a certain degree of shortness, as a general rule pigments that show this quality are not suited for making inks.

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[37] Underwood, Norman, and Sullivan, J. V., The chemistry and technology of printing inks, 1915.

An ink that flows well must also have the property of being drawn out into a string between the fingers, and this is called length. Thus each of these terms suggests or includes the other; they are both sometimes spoken of under the name viscosity.

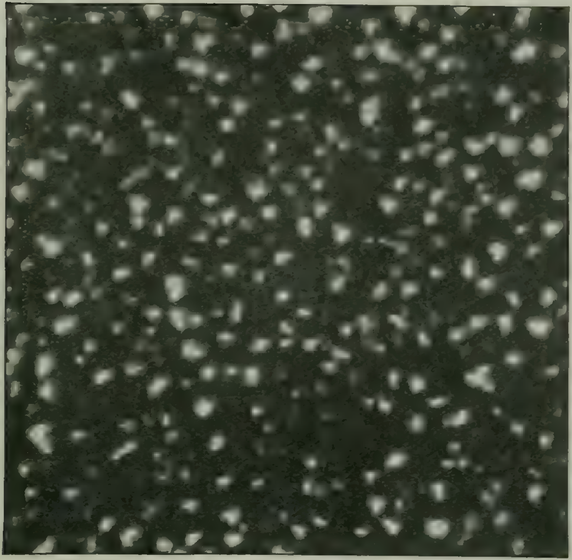
Apparently a pigment that gives a long ink is one that affects the original properties of the vehicle to a less extent than does an equal weight of a short pigment. To a large extent this question is probably one of fineness of subdivision, although the tendency of the particles of the pigment to form agglomerates may also affect it.

The particles are extremely small, below the resolving power of the microscope. Indications are that the average size of the particles of carbon black is about 100 millimicrons. Microscopic examination indicates that the particles of long blacks are slightly larger than those of short blacks, although the apparent difference in size may be due to the effect of diverse surface conditions on the diffraction of light. Exact measurements of the size of the particles have not been made; they would involve the counting of the number of particles in a small volume containing a known weight of black of known density, the measurement of the deflection in an electric field, and other measurements.

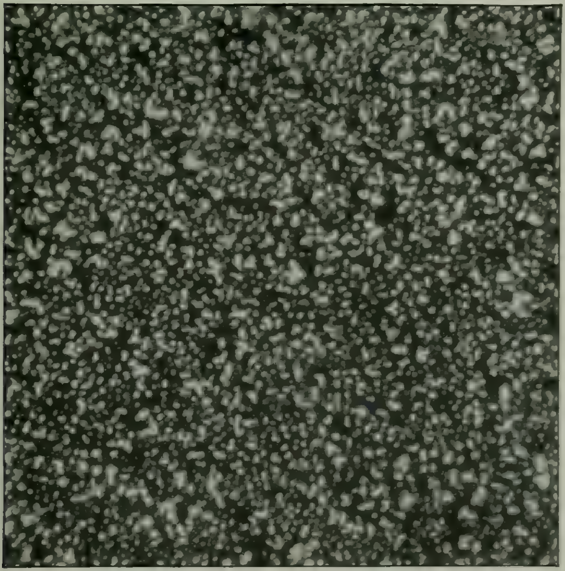
Dark ground illumination with the ultracondenser has proved to be the most satisfactory method of examination for most purposes. Examination by transmitted light in the ordinary manner does not distinguish between single particles and small agglomerates of particles; it is of advantage in showing up large agglomerates or particles of grit, and serves to show the relative opacity of the blacks. In general the higher the percentage of carbon in a black the blacker it looks under the microscope. Well-calcined lampblacks are more opaque than carbon black or than lampblacks containing much volatile matter.

Under the microscope freshly prepared mixtures of thin lithographic varnish with short and with long carbon black at first appear precisely similar. They consist of ultraparticles, or of agglomerates of two or three particles. After a few minutes, however, a decided difference is apparent. The short black has begun to agglomerate into groups of 20 or 30 particles, and in an hour over a hundred may be grouped together. These agglomerates are held loosely together and may be dispersed by pressing down on the cover glass, but they come together again in a few minutes.

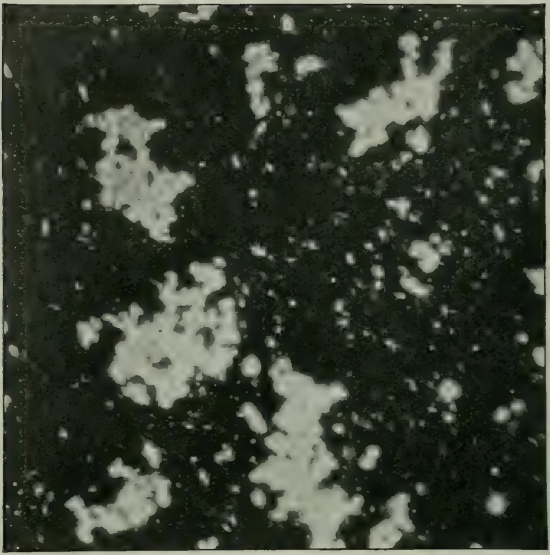
The long black on the contrary remains completely dispersed after several hours. Plate XI, *A*, shows a short black 18 minutes after preparation on the slide, Plate XI, *B*, shows the same black after 2 hours. Plate XII is the same as Plate XI, *B*, but magnified 2,000 diameters. *A* and *B*, Plate XIII, show a long black after several hours, magnifications 500 and 2,000, respectively. The concentra-



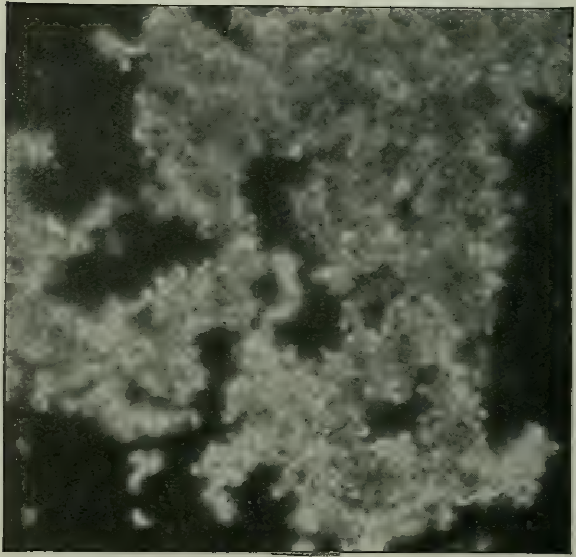
A. LONG BLACK TWO HOURS AFTER PREPARATION ON SLIDE. MAGNIFIED 500 DIAMETERS.



B. LONG BLACK FOUR HOURS AFTER PREPARATION ON SLIDE. MAGNIFIED 2,000 DIAMETERS.



A. LAMPBLACK, MAGNIFIED 500 DIAMETERS.



B. LAMPBLACK, MAGNIFIED 2,000 DIAMETERS.

tion of black in oil on the slide is about 1 part black to 1,000,000 parts oil.

Long blacks are usually made with cylindrical burners and a cool flame, a method that tends to produce a black high in volatile matter. It seems probable that these absorbed impurities prevent the carbon particles from agglomerating. In support of this conclusion, it has been found that if a long black be treated with steam at 500° C. so that the occluded matter is burned off, the black forms a distinctly thicker mixture in oil and is seen to be agglomerated under the microscope. Conversely, if a definite quantity of a short black is treated with a dilute alcoholic solution of tannin and mixed with oil after the alcohol has evaporated, it makes a much more fluid mixture than an equal amount of untreated black.

The tendency to agglomerate is modified materially by the character of the vehicle in which the blacks are suspended. In a thick viscous varnish no agglomeration is noticeable after several hours. Small amounts of metal soaps in a thin varnish tend to cause agglomeration even in the long blacks. Lampblack shows the tendency to agglomerate fully as much as do short carbon blacks, yet lampblacks as a rule make long inks. It is evident, therefore, that the tendency to agglomerate does not entirely explain the difference in the behavior of different blacks; surface forces between the vehicle and the particles of black probably play a part, and of course the size of the particles must be of importance. Measurement should be made of the size of particles of various carbon blacks and lampblacks.

Under the microscope lampblack and the different grades of carbon black look much alike. Lampblack is sometimes a little blacker, more opaque than the carbon black, probably according to the amount of carbon in the particle. Some blacks have a larger percentage of coarse material than others, but the divergence in properties is probably due to a difference in the constitution of the ultra particles, possibly a difference in size, in attraction between the particles, and in surface energy at the oil-black interface. In carbon blacks the difference in surface condition is apparently due to the presence of adsorbed gases and combined oxygen. In lampblacks a similar condition obtains. Calcining a lampblack at too high a temperature and removing too much of the empyreumatic matter and adsorbed gases produces a black that makes a short ink. Plate XIV, *A* and *B*, shows lampblack at 500 and 2,000 diameters, respectively.

Blacks which give long ink then probably consist of slightly larger particles than those which make a shorter ink, hence exposing less surface per unit weight and requiring less oil to form a mixture of a given consistency. Furthermore, difference in surface conditions, due to the fact that long blacks contain a high percentage of adsorbed gases, probably influences the properties of the mixture of the black with oil. Microscopic examination of dilute mixtures of black and oil shows one effect of this difference in surface conditions, in the tendency of the blacks containing little adsorbed impurities to agglomerate, while the blacks containing large amounts of volatile matter remain dispersed.

This discussion of the properties of mixtures of carbon black and oil has been speculative and little experimental evidence has been presented; but it is hoped that the discussion will stimulate interest in the problem and further investigations.

SUMMARY.

It has been pointed out in this paper that the present process of making carbon black recovers only a small percentage of the carbon in the gas, yet no other process in practical operation produces a material with properties similar to carbon black. Inability to secure carbon black would deal a serious blow to the printing industry, and would probably inconvenience rubber manufacturers and others. On account of the diminishing supply of natural gas, developmental work should be conducted on more efficient methods of manufacture and production from other materials. The problem is not an easy one, and developmental work should probably not endeavor to improve the present process but should investigate entirely new methods, as for example, the decomposing of gas or of other hydrocarbons in the absence of air. The uses of carbon black have also been discussed, testing methods have been explained, and a brief account has been given of preliminary work on microscopic and chemical differentiation of blacks giving "long" and "short" inks.

SELECTED BIBLIOGRAPHY.

This bibliography was compiled in March, 1919. Additional references were later secured from a bibliography on lampblack by the Carnegie Library of Pittsburgh.

In abridgments of specifications of English patents in the English patent office for the periods 1855–66, 1867–76, 1877–83, 1884–88, 1889–92, 1893–96, 1897–1900, 1901–04, 1905–08, lampblack is covered by class 90.

1844—1874.

Bottenberg, J. H. Apparatus for the manufacture of lampblack. U. S. patent 153234, July 21, 1874. Has a revolving, water-cooled cylinder with burners on interior.

Clark, Edward. Improvement in the manufacture of lampblack and colophane. U. S. patent 6001, Jan. 2, 1849. Manufactures lampblack and colophane by heating resin.

Child, R. S. Utilization of coal tar. U. S. patent 32753, July 9, 1861.

Farrar, Alonzo. Apparatus for the manufacture of carbon black. U. S. patent 154467, August 25, 1874. Has a rotary water vessel with a stationary scraper.

Howarth, John. Manufacture of carbon black from natural carburetted hydrogen gas (natural gas). U. S. patent 131446, Sept. 17, 1872. Reissue 6937, Feb. 22, 1876. A pan of water is placed upon a soapstone slab to reduce the temperature of the carbon black that is deposited.

Lundgren, J. E. Mode of pulverizing and preparing for use, coal, etc. U. S. patent 42257, April 5, 1864. Production of a substitute for lampblack by pulverizing carbonaceous material by means of a ball mill.

Matlack, Mahlon. Improved apparatus for the manufacture of lampblack. U. S. patent 75943, Mar. 24, 1868.

Millochau, Adolph. Manufacture of lampblack. U. S. patent 72068, Dec. 10, 1867. Condenses carbonaceous vapors upon a surface that is directly over a flame and is kept cool by artificial means.

——— Manufacture of lampblack. U. S. patent 84131, Nov. 17, 1868. Lampblack is placed in a vessel containing oil to be burnt, and a wick is not used as it often becomes gummed from collection of tar.

Mini, J. G. Improvement in making lampblack. U. S. patent 3824, Nov. 13, 1844.

Perlee, R. N. Manufacture of lampblack. U. S. patent 72078, Dec. 10, 1867. Introduces a current of air from pump to burner in which oil is burned.

Prenatt, Augustus. Improvement in the manufacture of lampblack. U. S. patent 50493, Oct. 17, 1865.

Rogers, John. Improvement in apparatus for making lampblack. U. S. patent 146951, Jan. 27, 1874.

Roth, J. A. Making lampblack. U. S. patent 17519, June 9, 1857.

Tait, A. H. Manufacture of carbon black for pigment. U. S. patent 148778, Mar. 17, 1874. Carbonization of sugar, starch, etc.

1875—1884.

Blood, E. R. Machine for making carbon or gas black. U. S. patent 269378, Dec. 19, 1882. A scraper curved to conform more or less to a peripheral section of the cylinders and attached by its middle to a crosshead adapted to be moved back and forth between the cylinders.

See also Hallock, J. K.

Cornell, J. M. Improvement in lampblack apparatus. U. S. patent 210672, Dec. 10, 1878.

Dingler's polytechnisches Journal. Ueber die Gewinnung von Lampenschwarz aus natürlichen Kohlenwasserstoffen. Bd. 231, 1878, pp. 177–178.

Dysart, J. T. Apparatus for manufacturing carbon black. U. S. patent 266953, Oct. 31, 1882. Uses a depositing surface that consists of a metallic surface faced with asbestos.

Falconer, William. Machine for the manufacture of carbon black. U. S. patent 277472, May 15, 1883. Consists of stationary burners, rotating horizontal table perforated for ventilation, stationary sectional scraper, receptacle for receiving black, and conveyor for removing carbon black from receptacle.

Fales, L. S., and Neff, Peter. Manufacture of lampblack. U. S. patent 160759, March 16, 1875. Made from acid sludge by treating first with steam to remove acid and subsequently burning recovered oils by the use of wicks.

Gentele, J. G. Lehrbrech der Farbenfabrikation. 1880. 661 pp.

Hallock, J. K. Machines for making lampblack. U. S. patent 195709, Oct. 2, 1877. A circular depositing plate and revolving burners are inclosed in a hood for regulating the supply of air to burners.

Hallock, J. K., and Blood, E. R. Machines for making lampblack. U. S. patent 205955, July 16, 1878. A revolving cylinder arranged above burners so that the flame will impinge upon the exterior surface of the cylinder and deposit carbon.

Heumann, R. Presence of carbon particles in the flame. Ann. Chem., vol. 181, 1876, p. 129; vol. 182, 1876, p. 1; vol. 183, 1876, p. 102; vol. 184, 1876, p. 206.

HOWARTH, JOHN. Apparatus for the manufacture of lampblack. U. S. patent 161039, March 23, 1875. Uses soapstone tile as deposition surface for carbon, movable burners, and moving scrapers.

MALLET, J. W. Lampblack from natural gas, 1880. United States Centennial Commission, International exhibition 1876. Reports and awards group, vol. 4, p. 111.

NEFF, PETER, and FALES, L. S. Improvement in apparatus for the manufacture of carbon or lampblack. U. S. patent 159440, Feb. 2, 1875.

———. Manufacture of lampblack. U. S. patent 160786, Mar. 16, 1875. The combined burning of carbonaceous gases and crude petroleum or dead oils.

———. Improvement in gas burners for the manufacture of lampblack. U. S. patents 160787 and 160789, Mar. 16, 1875.

———. Manufacture of lampblack. U. S. patent 160788, Mar. 16, 1875. The carbon black burners are placed in cells, the bells or domes of which are enveloped with a wire gauze.

———. Improvement in apparatus for manufacture of lampblack. U. S. patents 162492 and 162679, Apr. 27, 1875; 163027, May 11, 1875; 166936, Aug. 24, 1875.

———. Lampblack apparatus. U. S. patent 162679, April 27, 1875. Relates to the installation of funnel-shaped hoods above burners that are connected to a bag house to catch flocculent carbon black that is carried away by fumes.

———. Lampblack apparatus. U. S. patent 166936, Aug. 24, 1875. Apparatus having a convex depositing surface, with burners located beneath which are adjustable in order to facilitate the removal of black.

———. Apparatus for making lampblack. U. S. patent 163027, May 11, 1875. The use of condensing domes located over carbon black burners whereby the surface is always maintained cool.

———. Apparatus for manufacture of lampblack. U. S. patent 162492, April 27, 1875. Consists of a suitable burning chamber that is connected to a water tank containing two or more flues.

———. Gas burners for the manufacture of lampblack. U. S. patent 160787, March 16, 1875. Describes an improvement in a gas burner used in making carbon black.

———. Gas burners for the manufacture of lampblack. U. S. patent 160789, March 16, 1875. Relates to burner employed in the manufacture of carbon black.

——— Manufacture of lampblack. U. S. patent 172046, Jan. 11, 1876. Description of a new design of gas burner used in making carbon black.

——— Scrapers for lampblack apparatus. U. S. patent 176476, Apr. 25, 1876. A number of stiff inflexible metallic scrapers attached at one extremity to a rigid body.

——— Scrapers for lampblack apparatus. U. S. patent 176477, Apr. 25, 1876. Describes a vertical spring-pressed metallic scraper having flanged working extremities and loosely hinged to opposite sides of the cross bar.

——— Improvement in the manufacture of lampblack, No. 172046, Jan. 11, 1876; improvement in scrapers for lampblack apparatus, U. S. patents 176476, Apr. 25, 1876; 176477, Apr. 25, 1876; 176478, Apr. 25, 1876.

——— Scrapers for lampblack apparatus. U. S. patent 176478, Apr. 25, 1876. Overlapping metallic scrapers, flexible and elastic in themselves, and curved upward from a rigid bearing.

——— Machinery for making lampblack. U. S. patent 197395, Nov. 20, 1877. The depositing surface is attached to a car or vehicle whereby it may be moved relative to burners.

——— Apparatus for the manufacture of lampblack. U. S. patent 221417, Nov. 11, 1879. A compartment provided with adjustable openings in floor to regulate the passage of air.

See also Fales, L. S.

Neff, Peter, and Fales, L. S. Apparatus for the manufacture of carbon or lampblack. U. S. patent 159440, Feb. 2, 1875. A series of rooms communicating by openings alternately near top and bottom. Each room has a suspended hinged apron for intercepting and collecting the soot.

Plumbly, F. K. Apparatus for the manufacture of lampblack. U. S. patent 301518, July 8, 1884. Gas is burned under revolving pans containing water. Each pan is arranged with a separate hood to which is connected an exhaust fan.

Rogers, John. Improvement in processes and apparatus for making lampblack, U. S. patent 186498, Jan. 23, 1877.

Santos, J. R. Analysis of lampblack made from the natural hydrocarbon gas of the Ohio petroleum region. Chem. News, vol. 38, 1878, pp. 94–95.

Seymour, M. J. Process of and apparatus for manufacturing lampblack. U. S. patent 278749, June 5, 1883. Consists in forcing the smoke from burning hydrocarbons through a suitable liquid or a moist vapor and then evaporating the liquid or condensing the vapor to recover the finely divided carbon.

Shoemaker, G. G. Apparatus for the manufacture of carbon black. U. S. patent 292696, Jan. 29, 1884. Lampblack is deposited on interior surface of a conical steel apparatus which is water cooled. The lampblack is automatically scraped from the cone.

Winslow, H. B. Improvement in apparatus for the manufacture of lampblack, U. S. patent 222337, Dec. 2, 1879.

1885–1894.

Andes, L. E. Die Fabrikation der Stiefelwichse und der leder Conservirungsmittel. 1893. 366 pp.

Binney, Edwin. Apparatus for the manufacture of carbon black. U. S. patent 453140, May 26, 1891. Consists of a furnace, cylindrical chamber, and conveyor for removing the carbon black located at bottom of chamber.

Blood, E. R. Lampblack machine. U. S. patent 480990, Aug. 16, 1892. Has circular plates as the depositing surface with an opening between edges and gas burners below opening.

Blood, A. R., Blood, B. H., and Blood, E. R. Apparatus for manufacture of lampblack. U. S. patent 387487, Aug. 7. 1888. Consists of a number of horizontal rotating deposit rings, with an annular row of gas burners, arranged centrally under the deposit ring, and scrapers operating to remove the black automatically from the ring.

Blood, E. R., and Wenstrau, S. P. Lampblack machine. U, S. patent 403174, May 14, 1889. A deposition plate for carbon black having a vent directly over flame for the escape of the products of combustion, with a secondary plate supported over the vent.

——— Process of making lampblack. U. S. patent 478268, July 5, 1892. A perforated plate for catching carbon black is used.

Cabot, G. L. Apparatus for the manufacture of lampblack. U. S. patent 468510, Feb. 9, 1892. Apparatus provided with rotating burners, fixed collecting plate, and radial trough traveling under the plate and surrounding the scrapers for removing the accumulated black.

——— Manufacture of lampblack. U. S. patent 491923, Feb. 14, 1893. Gas is enriched with oil and the mixture superheated before being burned under plates for collecting the carbon.

Cabot, Samuel, jr. Apparatus for the manufacture of lampblack. U. S. patent 388475, Aug. 28, 1888. A revolving multiburner lamp is provided with an external ring of angle iron braced to a central standard, with burner tubes supported thereto, and an endless driving chain resting in the angle of the external ring and encircling the pulley of a suitable motor.

DIETRICH, TOBIAS. Lampblack machine. U. S. patent 431881, July 8, 1890. A machine for preparing carbon black is in an inclosed chamber in which an endless metallic belt is arranged as the depositing surface.

DREYER, ROBERT. Apparatus for the manufacture of lampblack. U. S. patent 444315, Jan. 6, 1891. Manufactures carbon black with the simultaneous generation of steam.

DYSART, J. T. Apparatus for manufacturing carbon black. U. S. patent 343446, June 8, 1886. Introduces gas into a carbonaceous liquid through a series of small openings, then conducts gas to burners, and carbon black is deposited on condensing surfaces.

ESTER, G. L. Lampblack machine. U. S. patent 507220, Oct. 24. 1893. A machine having two accumulator wheels arranged in a common horizontal plane, and each having toothed edges. Wheels are moved by a worm gear that simultaneously intermeshes with toothed peripheries of both wheels.

ESTER, H. J. C. Lampblack machine. U. S. patent 486097, Nov. 15, 1892. The carbon is deposited upon the inside and outside of the rim of a revolving wheel.

IRVINE, ROBERT. Condensation of carbon particles in smoke. Jour. Soc. Chem. Ind., vol. 9, 1890, pp. 1110–1112.

JAMES, J. E. Lampblack or carbon-black machine. U. S. patent 521797, June 26, 1894. Apparatus with a collecting plate having an air vent opening and a damper for governing opening that is automatically controlled by the scraper.

KOHLER, HIPPOLYT. Die Fabrikation des Russes und der Schwarze, 1889. 105 pp.

LANGVILLE, L. S. Carbon product. U. S. patent 475062, May 17, 1892.

MCNUTT, L. J. Hydrocarbon-gas-black machine. U. S. patent 481240, Aug. 23, 1892. The carbon is deposited upon moving channel irons, which are automatically scraped.

MCTIGHE, J. J. Apparatus for manufacturing lampblack. U. S. patent 346168, July 27, 1886. Comprises a depositing chamber, with means of cooling same in combination with a retort wherein hydrocarbon vapors may be decomposed.

——— Manufacturing carbon black. U. S. patent 346169, July 27, 1886. Producing carbon black from gas by the action of intense heat without combustion of gas.

NEFF, PETER. Apparatus for manufacturing lampblack. U. S. patent 314706, Mar. 31, 1885. Stationary burners are used and a horizontally rotating table, the under surface of which is concave.

——— Apparatus for manufacturing lampblack. U. S. patent 314707, Mar. 31, 1885. Gas is burned under a horizontal rotating turntable mounted on flanged wheels that travel on a circular track.

——— Apparatus for manufacturing lampblack. U. S. patent 319604, June 9, 1885. The apparatus is provided with a horizontally rotating surface constructed to form an inverted chamber for the reception of carbon dioxide.

——— Apparatus for the manufacture of lampblack. U. S. patent 319605, June 9, 1885. The machine is equipped with a revolving black collector mounted on a hollow shaft, which is provided below collector with lateral openings and is used as a ventilating chimney.

——— Apparatus for the manufacture of lampblack. U. S. patent 319606, June 9, 1885. Relates to a machine in which a collector is mounted on a hollow standard that revolves around an upright stationary column.

OPPLER, T. Die Unfallverhutungs-Austellung in Berlin in ihrer Bedeutung für die chemische Industrie: Chem. Ind., vol. 12, 1889, p. 532; (Lampblack manufacture)—abstract—Jour. Soc. Chem. Ind., vol. 9, 1890, p. 272.

Rerdon, P. F. Hydrocarbon-gas-black machine. U. S. patent 523945, July 31, 1894. The machine has deposit rings having a semicircular underface, and an annular groove around the periphery of the top. The rings have ratchet teeth in the bottom of the groove.

Rhodes, S. L. Lampblack machine. U. S. patent 497686, May 16, 1893. The machine has a concave depositing surface and a reciprocating carriage supported in proper relation to surface and to burners mounted on carriage.

Salberg, Swain. Apparatus for making lampblack. U. S. patent 486127, Nov. 15, 1892. The depositing surface is V-shaped for collecting the carbon.

Schermerhorn, D. M., **Schermerhorn**, P. V., and **Schermerhorn**, S. P. Apparatus for the manufacture of gas black. U. S. patent 489332, Jan. 3, 1893. Carbon black is deposited upon a T-shaped beam. The scraper box moves along this depositing surface, but both beams and burners are stationary.

Smithells, Arthur. Note on the structure of luminous flames. Jour. Chem. Soc., vol. 61, 1892, pp. 217–226.

Smithells, Arthur, and **Ingle, Harry.** The structure and chemistry of flame. Jour. Chem. Soc., vol. 61, 1892, pp. 204–216.

Wagner, Rudolph von. Manual of chemical technology, 1892, 968 pp.

Wilson, John. Apparatus for manufacturing lampblack. U. S. patent 346973, Aug. 10, 1886.

1895–1904.

Bersch, Josef. The manufacture of mineral and lake pigments. 476 pp., 1901

Cabot, Samuel. Process of recovering flocculent carbon. U. S. patent 581391, Apr. 27, 1897. Consists in treating the carbonaceous residues from the manufacture of prussiates with an aqueous solution of a mineral acid.

Frank, Adolph. Process of making carbon pigment. U. S. patent 682249, Sept. 10, 1901. Consists in reacting on a carbide of a metal with an oxide of carbon.

Houze, Luc, and **Dhé, Charles.** An apparatus for making lampblack. U. S. patent 668045, Feb. 12, 1901. An apparatus with a combustion chamber, a collecting plate in the chamber being provided with a damper for controlling the air.

Hubon, E. Le noir d'acetylene et ses derives, 1900. Mém. Soc. Ing. Civ. France, 1900, pt. 1, p. 680.

Hubou, L. J. E. Process of making lampblack. U. S. patent 671672, Apr. 9, 1901. Consists in exploding acetylene under pressure out of contact with air by means of an electrical, chemical, or calorific source of energy.

——— Process of making lampblack. U. S. patent 673185, Apr. 30, 1901.

Jaubert, G. F. Acetylene and the manufacture of mineral black. Scientific Am. Supp., vol. 48, 1899, p. 19905.

Mann, J. H. Apparatus for making carbon black. U. S. patent 706430, Aug. 5, 1902. The apparatus has a horizontally disposed shaft and carbon-collecting wheels that have wedge-shaped peripheries.

——— Machine for making lampblack. U. S. patent 754471, Mar. 15, 1904. The apparatus has a reversible plate on a pivotal support. Both sides of the plate form depositing surfaces.

Mann, J. L. Lampblack machine. U. S. patent 654171, July 24, 1900. The apparatus has as the depositing surface a corrugated roller that is exposed to a flame, and has means for scraping rollers.

——— Lampblack apparatus. U. S. patent 706429, Aug. 5, 1902. The machine is made up of a horizontal series of members mounted to rotate in individual parallel vertical planes, that are separated by vertical interspaces, each member being arranged with its peripheral edge over the flame.

Ogilez, D. J. Process of producing lampblack. U. S. patent 706001, July 29, 1902.

Parry, E. J., and **Coste**, J. H. The chemistry of pigments, 280 pp., 1902.

PORSCH, F. W. Apparatus for the manufacture of carbon black. U. S. patent 726341, Apr. 28, 1903. A machine provided with a depositing-plate comprising two rings, each having beveled faces and the outerlying ring elevated above the inner ring.

REARDON, P. F. Apparatus for making lampblack. U. S. patent 663395, Dec. 4, 1900. A machine having horizontal revolving deposit plates arranged in two rows provided with burners and scrapers. A hopper extending the entire length of the rows carries away accumulated carbon.

SANDERS, J. F. Apparatus for making lampblack, U. S. patent 660973, Oct. 30, 1900. Production of lampblack. Sci. Am. Supp., vol. 48, 1899, p. 19800.

THALWITZER, R. Manufacture of soot by combustion of a mixture of gases with hydrocarbon vapors. British patent 22567, Nov. 11, 1899.

WEGELIN, GOTTFRIED. Apparatus for manufacturing lampblack, U. S. patent 664916, Jan. 1, 1901. Apparatus for making lampblack, U. S. patent 688215, Dec. 3, 1901.

——— Process of making lampblack. U. S. patent 673185, Apr. 30, 1901. Consists in compressing a column of flame to a smaller cross section, by means of an annular radial current of air applied against the flame.

——— Process of making lampblack. U. S. patent 680093, Aug. 6, 1901. A process of manufacturing lampblack and controlling the specific gravity of the product which consists in controllably abstracting heat from the flame of combustion by passing the flame through a restricted cooling flue that is cooled externally at determined points varying with the quality of product desired.

WILLIAMS, J. J. Automatic lampblack machine. U. S. patent 601389, Mar. 29, 1898. A machine having a frame, a series of depositing plates, each provided with a cooling chamber on its upper surface, a series of collectors movably mounted under plates, and a conveyor for removing accumulated carbon.

1905-1914.

ACHESON, E. G. Method of treating amorphous bodies and product thereof. U. S. patent 1082386, Dec. 23, 1913.

AMERICAN GASLIGHT JOURNAL. Lampblack—a composite paper by several members. Vol. 87, 1907, p. 620.

ANDES, L. E. Treatment of paper for special purposes, 1907.

ARSEM, W. C. Transformation of other form of carbon into graphite. Trans. Am. Electro-chem. Soc. vol. 20, 1911, p. 105. Chem. Eng. vol. 14, 1911, p. 400. Jour. Ind. Eng. Chem. vol. 3, 1911, p. 799.

BONE, W. A. Gaseous combustion. Chem. News, vol. 97, 1908, pp. 196–8, 212–5; vol. 102, 1910, pp. 271–73, 284–6, 297–8, 309–11, 323–5; vol. 112, 1915, pp. 211–7, 223–5. Trans. Royal Soc. London, vol. 215, 1915, pp. 273–318. Jour. Chem. Soc. vol. 87, 1905, p. 910, 1236, vol. 89, 1906, p. 652, 660, 939, 1614.

BOSCH, K. Manufacture of lampblack from hydrocarbons or their mixtures by decomposition, German patent 268291, July 14, 1911. Method of obtaining soot from hydrocarbons such as acetylene, German patent 270199, Feb. 8, 1913.

BUTLER, D. B. Lampblack production and uses. Min. and Eng. World, vol. 35, 1911, pp. 864–865.

CABOT, G. L. Lampblack and carbon black. Eighth Internat. Cong. of App. Chem., vol. 12. p. 13–31, 1912. On the preparation of carbon blacks from natural gas in America. Jour. Soc. Chem. Ind., vol. 13, 1894, pp. 128–130.

DAVEY, C. W. B. et al. Treatment of brine at low temperatures and manufacture of lampblack. British patent 5685, Mar. 13, 1908.

DAVIS, W. H. Lampblack machine. U. S. patent 859750, July 9, 1907. A machine having a cylinder as the depositing surface. Air is forced through the cylinder and discharged into a combustion chamber.

Diffenbach, O., and Moldenhauer, W. Improving lampblack by means of oxidizing agents. German patent 263292, Feb. 18, 1912.

Doyle, H. L. Collodial suspension of graphite. Jour. Phys. Chem., vol. 17, 1913, p. 390.

Faraday Society. Colloids and their viscosity. A general discussion, including papers by Wolfgang Ostwald, Victor Henri, Wolfgang Paule, H. Freundlich, and Emil Hatschek. Transactions, vol. 9, 1913, p. 34–107.

Fernekes, Gustave. Method of producing carbon or lampblack. U. S. patent 1066894, July 8, 1913. Consists in subjecting methane to a temperature of not less than 1,300° C.

Frank, Adolf. Gewinnung von Russ und Graphit aus Acetylen und Metallcarbiden. Chem. Ztg., vol. 29, pt. 2, 1905, p. 1044. Abstract translation, Jour. Soc. Chem. Ind., vol. 24, pt. 2, 1905, p. 1117.

Frost, W. H., and Joshua J. Nix. Process for the production of carbon black together with combustible gas, U. S. patent 977000, Nov. 29, 1910.

Gollmert, Max. Process of manufacturing finely divided or amorphous carbon from mixtures of hydrocarbons and CO or CO_2. German patent 212202, Nov. 1, 1907.

Herman, E. Breaking down light hydrocarbons with exclusion of air. German patent 290883, Oct. 23, 1914.

Hurst, G. H. Painters' colors, oils, and varnishes. 1913. 519 pp.

Journal of Gas Lighting. Influence of surface decomposition of hydrocarbons. Vol. 106, 1909, pp. 300.

——— Methane equilibrium. Vol. 117, 1912, p. 21.

Koppers. Process of separating carbon from hydrocarbons by passing through heated retorts. French patent 356,351, July 24, 1905.

Lampblack, Ltd. Lampblack from incomplete combustion of oil. British patent 17223, July 14, 1912.

Machtolf, Josef. Apparatus for manufacturing soot from hydrocarbons by rupture with electric sparks. British patent 14601. 1906.

——— Process for the production of amorphous carbon. U. S. patent 872949, Dec. 3, 1907. Heating an explosive mixture of hydrocarbon gases to their ignition temperature.

——— Apparatus for producing carbon. U. S. patent 872950, Dec. 3, 1907. Igniting an explosive mixture of hydrocarbons. A conduit connects the decomposition chamber with the collecting compartment.

——— Apparatus for making lampblack from hydrocarbons by rupture with electric sparks. German patent 194301. 1908. Apparatus for making amorphous carbon by decomposition of hydrocarbons. German patent 207520. 1909. Process of making lampblack with very valuable properties. German patent 194939. 1908.

——— Carbon and hydrogen by explosion of hydrocarbons. British patent 13685, 1909.

Maire, Frederick. Modern pigments and their vehicles. 266 pp. 1908.

Maiser, Franz. Apparatus for making oil-fuel lampblack. German patent 203711. 1909.

——— Lampblack. German patent 288990, Mar. 10, 1914.

Mann, J. L. Apparatus for making lampblack. U. S. patent 865603, Sept. 10, 1907. A machine with a carbon collecting member having a continuous surface, the different portions of which are exposed successively to a flame and provided with flanges forming a flame guard.

Mayer, M., and Altmayer, V. Synthesis of methane with calcium hydride. Ber. Deut. chem. Gesell., Jahrg. 41, 1908, pp. 3074–3080.

Morehead, J. M. Process of making lampblack from acetylene. U. S. patent 779728, Jan. 10, 1905. Consists in exploding mixture of acetylene and oxygen that has been compressed.

——— Process of dissociating acetylene. U. S. patent 986489, Mar. 14, 1911.

Ogilvy, D. J. Process of producing black or dark carbonaceous pigments. U. S. patent 785696, Mar. 21, 1905. Impinging carbonaceous flames produced by a moving source on the surface of water in a stationary condition.

——— Process of producing carbonaceous pigments. U. S. patent 813911, Feb. 27, 1906. Impinging carbonaceous flames, produced by a moving source on water in a state of motion.

Plausen, H. Pure finely divided carbon from coal or wood charcoal. British patents 17729, 17731, 17732, 1913.

Pictet, R. P. Preparation of hydrogen and lampblack from acetylene. German patent 255733, Oct. 22, 1909.

——— Continuous production of hydrogen and carbon from acetylene. British patent 24256, Oct. 19, 1910.

Purtle, A. D., and Rowland, I. E. Process of making carbon black. U. S. patent 866883, Sept. 24, 1907. Subjects gas under pressure in closed retort heated to 800° C. until the gas is decomposed and carbon is deposited in a flocculent condition on the interior walls of the retort.

——— Apparatus for producing carbon black. U. S. patent 877596, Jan. 28, 1908. For the thermal decomposition of gas in which the hydrogen is utilized in heating the decomposition chamber.

Redwood, Boverton. Petroleum, 1906. Discusses lampblack, p. 698.

Rütgerswerke, Akt-Gesell. Process of manufacturing lampblack from mineral coal tar. German patent 208600, May 24, 1908.

Sadtler, S. P. Industrial organic chemistry, 601 pp., 1912. Discusses lampblack, p. 31.

Salberg, Swain. Apparatus for making lampblack. U. S. patent 801743, Oct. 10, 1905. A series of annular pans, each with a ring of gear teeth around its upper end; the teeth of one pan matching with teeth of another so that when the driving mechanism is connected to one pan it will be transmitted throughout the series.

Sharts, T. P. Apparatus for producing carbon. U. S. patent 819606, May 1, 1906.

Siemens & Co. Production of lampblack. German patent 295517, 1914.

——— Société Anon. des combustibles industriels. Pure carbon from hydrocarbons such as coal tar, tar oil, etc. German patent 291727, Feb. 3, 1914.

Smith, J. E. Process for obtaining carbon black from peat. U. S. patent 916049, Mar. 23, 1909.

Snee, J. A. Method of producing carbon black. U. S. patent 1036362, Aug. 20, 1912. Consists in passing a stream of hydrocarbon gas horizontally through a highly heated flame-excluded zone with a lower temperature at the bottom than at the upper part.

Stewart, G. W. Resistance temperature coefficient and the coefficient of expansion of lampblack. Phys. Rev., vol. 26, 1908, p. 333.

Stutler, B. B. The largest lampblack factory, Oil and Gas Jour., vol. 10, pt. 1, 1911, p. 2.

Sweeny, J. M. Machine for making carbon black. U. S. patent 836948, Nov. 27, 1906. Has a horizontal plate upon which gas flames are directed at an acute angle.

Thieme, Bruno. Electric production of lampblack. Ztschr. Elektrochem., vol. 18, 1912, p. 131.

——— Electrical deposition of lampblack from flame on a wire screen. German patent 256675. Jan. 11, 1912.

Thompson, G. W. Coating-power and hiding-power of paints, Proc. Eighth Int. Cong. Appl. Chem., vol. 25, 1912, p. 795.

——— Scientific preparation and application of paint. Jour. Ind. Eng. Chem., vol. 2, 1910, p. 87.

Thorpe, Edward. A dictionary of applied chemistry, ed, 1912–13. Lampblack, vol. 1, pp. 664–665.

Wegelin, Gottfried. Apparatus for making lampblack. U. S. patent 807646, Dec. 19, 1905. The oil is agitated by a mechanical stirrer and air current in the combustion chamber.

——— Utilizing power from explosion of acetylene (in manufacture of lampblack). German patent 201262, Jan. 9, 1907.

——— Apparatus for making lampblack. U. S. patent 897439, Sept. 1, 1908.

Zerr, George, and Rubencamp, R. Treatise on color manufacture, 605 pp. Griffin, 1908. Discusses lampblacks (soot pigments), pp. 415–425.

1915—1919.

Acheson, E. G. Method of deflocculating solid materials. U. S. patent 1223350, Apr. 24, 1917.

Andes, L. E. Oil colors and printers' inks. 1918. 212 pp.

Averill, C. C. Lampblack and hydrochloric acid, U. S. patent 1238734, Sept. 4, 1917.

Bacon, R. F., Brooks, B. T., and Clark, Hugh. Manufacture of carbon black and hydrogen. U. S. patent 1220391, Mar. 27, 1917. A method of making lampblack and hydrogen by injecting a jet of liquid hydrocarbons into a zone heated to a temperature sufficient to flash hydrocarbons into their elements.

Bone, W. A. *See* under 1905–1914.

Brownlee, R. H., and Uhlinger, R. H. Process for the manufacture of hydrogen and carbon black. U. S. patent 1168931, Jan. 18, 1918. Methane is decomposed by bringing it into contact with a highly refractory material in vacuum at pressure. Carbon black is then separated from hydrogen.

Blardone, G. G., Nichols, C. W., and Bruquiere, Faurie. Substitute for lampblack, U. S. patent 1156742, Oct. 12, 1915.

Briggs, T. R. The tinting strength of pigments. Jour. Phys. Chem., vol. 22, 1918, p. 216.

Brownlee, R. H., and Uhlinger, R. H. Apparatus for manufacture of hydrogen and carbon black. U. S. patent 1265043, May 7, 1918. Apparatus for decomposing methane by bringing it into contact with a highly heated refractory material in the absence of air.

Cabot, G. L. Apparatus for making carbon black. U. S. patent 1162131, Nov. 30, 1915. A machine having laterally spaced, parallel, depositing-cylinders.

Davis, W. H. Lampblack machine. U. S. patent 1160862, Nov. 16, 1915. A flat perforated plate above ordinary rings collects the carbon black usually lost in flue gases.

Dowling, D. B. Utilizing natural gas. Bull. Canadian Mining Inst., June 1918, pp. 525–528. Describes gasoline absorption plant and carbon black plant in Wyoming.

Engineering. X-Rays and the structure of amorphous carbon. Vol. 104, 1917, pp. 594–596.

Evans, A. C., Wick Hampton, and Mitchell, P. J. Method of manufacturing finely divided carbon and by-products from coal pitch, U. S. patent 1175732, Mar. 14, 1916.

Fisher, H. A. Warns against crowding carbon-black industry, Nat. Pet. News, vol. 10, 1918, p. 64.

Garner, J. B. The chemical possibilities of natural gas, Proc. Nat. Gas. Assoc. of America, vol. 10, 1918, p. 136–169, Nat. Gas and Gasoline Jour., vol. 12, 1918, pp. 319–330; Gas Age, vol. 41, 1918, pp. 555–560; Am. Gas. Eng. Jour., vol. 108, 1918, pp. 489–495, 505–508; Chem. Eng., vol. 26, 1918, pp. 245–254.

Geer, W. C. Compounding rubber with lampblack, U. S. patent 1245700, Nov. 6, 1917.

Gerard, J. M. Process for the manufacture of carbon black and lampblack. U. S. patent 1278137, Sept. 10, 1918.

Hamilton, W. R. Trap for saving gas at oil wells. Tech. Paper 209, Bureau of Mines, 1919, p. 21.

Hershman, P. R. Comminuted carbon and process of making same, U. S. patent 1188936, Jan. 27, 1916.

Hirt, L. E. Manufacture of carbon or lampblack. U. S. patent 1264796, Apr. 30, 1918. Making carbon black by enriching burning gas with oil vapors.

Hutchins, T. W. S. Manufacture of lampblack. U. S. patent 1309070, July 8, 1919. Making lampblack from tar or oil.

Lewis, G. C. Method of treating finely subdivided material. U. S. patent 1263082, Apr. 16, 1918.

Malisoff, W., and Egloff, G. Methane. A very complete review of the literature. Jour. Phys. Chem., vol. 22, 1918, pp. 529–575.

McCourt, C. O., and Ellis, C. Gas black and hydrogen from methane. U. S. patent 1276385, Aug. 20, 1918.

Mitchell, C. A., and Hepworth, T. C. Inks, their composition and manufacture, 1916. 266 pp.

Mott, W. R. Process of manufacturing lampblack. U. S. patent 1259121, Mar. 12, 1918. Process of producing carbon black by heating a mixture of methane gas and carbon tetrachloride.

——— Process of purifying lampblack and making carbon articles. U. S. patent 1303362, May 13, 1919. Lampblack is heated in the presence of carbon tetrachloride.

National Petroleum News. Carbon-black plants follow discovery of gas in Morehouse Parish, La. June 11, 1919. p. 1/m.

Ogilvy, D. J. Carbon pigment base and process of making same, U. S. patent 1268142, June 4, 1918.

Oil and Gas Journal. Carbon-black industry is opposed by Smith, vol. 16, 1918, p. 32.

——— Gas wasted in production of carbon black, vol. 17, 1918, p. 48.

Pike, R. D. Lampblack refuse purification. Canadian patent 181082, Dec. 18, 1917.

——— Carbon and method of manufacturing same. U. S. patent 1262251, Apr. 9, 1918. Method of purifying lampblack refuse by washing, roasting, and pulverizing.

——— Carbon and method of recovering same from the waste product of oil cracking. U. S. patent 1285363, Nov. 19, 1918. Recovering lampblack from refuse product of oil-gas manufacture by washing, roasting, and pulverizing.

Schweizer, V. The distillation of resins and the preparation of resin products, resinates, lampblack, printing inks, etc., 1917. 212 pp.

Slater, W. E. Influence of different surfaces on the decomposition of methane. Jour. Chem. Soc., vol. 109, 1916, pp. 160–164.

Snelling, W. O. Lampblack. U. S. patent 1213915, Jan. 30, 1917. Apparatus for making carbon black by projecting a flame upon a depositing surface that is maintained at a temperature slightly above 100° C.

Szarvasy, E. Retort carbon by dissociation of methane. U. S. patent 1199220, Sept. 26, 1916.

TARUP, P. Process for production of finely divided carbon. Canadian patent 175937, Mar. 27, 1917.

TARCYZYNSKI, S. Collodial carbon and dissociation of organic liquids by the electric arc. Ztschr. Elektrochem., vol. 22, 1916, pp. 252–254; Jour. Soc. Chem. Ind., vol. 35, 1916, p. 889.

THIEME, B. Modern production of lampblack. Ztschr. Elektrochem., vol. 20, 1914, pp. 61–63.

THORP, F. H. Outlines of industrial chemistry, 1917, 665 pp.

TOCH. M. The chemistry and technology of paints, 1916. 366 pp. Discusses lampblack, pp. 98–99; carbon black, p. 100.

UNDERWOOD, N., and SULLIVAN, J. V. The chemistry and technology of printing inks, 1915.

UNITED STATES BUREAU OF STANDARDS. Composition, properties, and testing of printing inks. Circular 53. 1915.

WARTENBURG, VON. The methane equilibrium, Ber. Deut. chem. Gesell., vol. 40, 1907, p. 2134.

WEST, F. H. Sale of natural-gas carbon black increasing. Gas Age, vol. 42, 1918, pp. 535–536.

WYER, S. S. Natural-gas: Its production, service, and conservation. Smithsonian Institution, U. S. Nat. Mus. Bull. 102, part 7, 1918, pp. 59–62.

ZIMMERS, D. F., JESSOP, E. N., KOENIG, W. J., and GARNER, J. B. Process of manufacturing carbon black. U. S. patent 1307430, June 24, 1919. The black is made from natural gas.

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Technical Paper 185. Use of the interferometer in gas analysis, by F. M. Seibert and W. C. Harpster. 1918. 18 pp., 1 pl., 5 figs.

Technical Paper 209. Traps for saving gas at oil wells, by W. R. Hamilton. 1919. 34 pp., 3 pls., 16 figs.

Technical Paper 253. Effects of gasoline removal on the heating value of natural gas, by D. B. Dow. 1920. 23 pp., 2 figs.

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Technical Paper 72. Problems of the petroleum industry, results of conferences at Pittsburgh, Pa., August 1 and September 10, 1913, by I. C. Allen. 1914. 20 pp. 5 cents.

Technical Paper 87. Methods of testing natural gas for gasoline content, by G. A. Burrell and G. W. Jones. 1916. 26 pp., 7 figs. 5 cents.

Technical Paper 104. Analysis of natural gas and illuminating by fractional distillation in a vacuum at low temperatures and pressures, by G. A. Burrell, F. M. Seibert, and I. W. Robertson. 1915. 41 pp., 7 figs. 5 cents.

Technical Paper 109. Composition of the natural gas used in 25 cities, with a discussion of the properties of natural gas by G. A. Burrell and G. G. Oberfell. 1915. 22 pp. 5 cents.

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